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U. S. Forest Service Research Paper SE- 21 August 1966

RACIAL VARIATION IN SLASH PINE AS AFFECTED BY CLIMATIC FACTORS

by

A. E. Squillace

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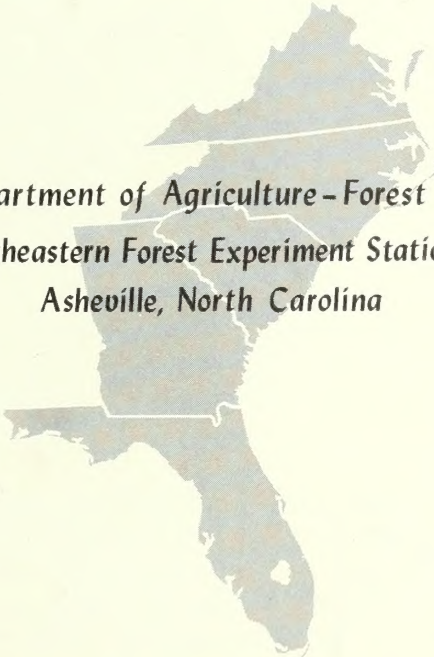

U.S. Department of Agriculture - Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

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ACKNOWLEDGMENT

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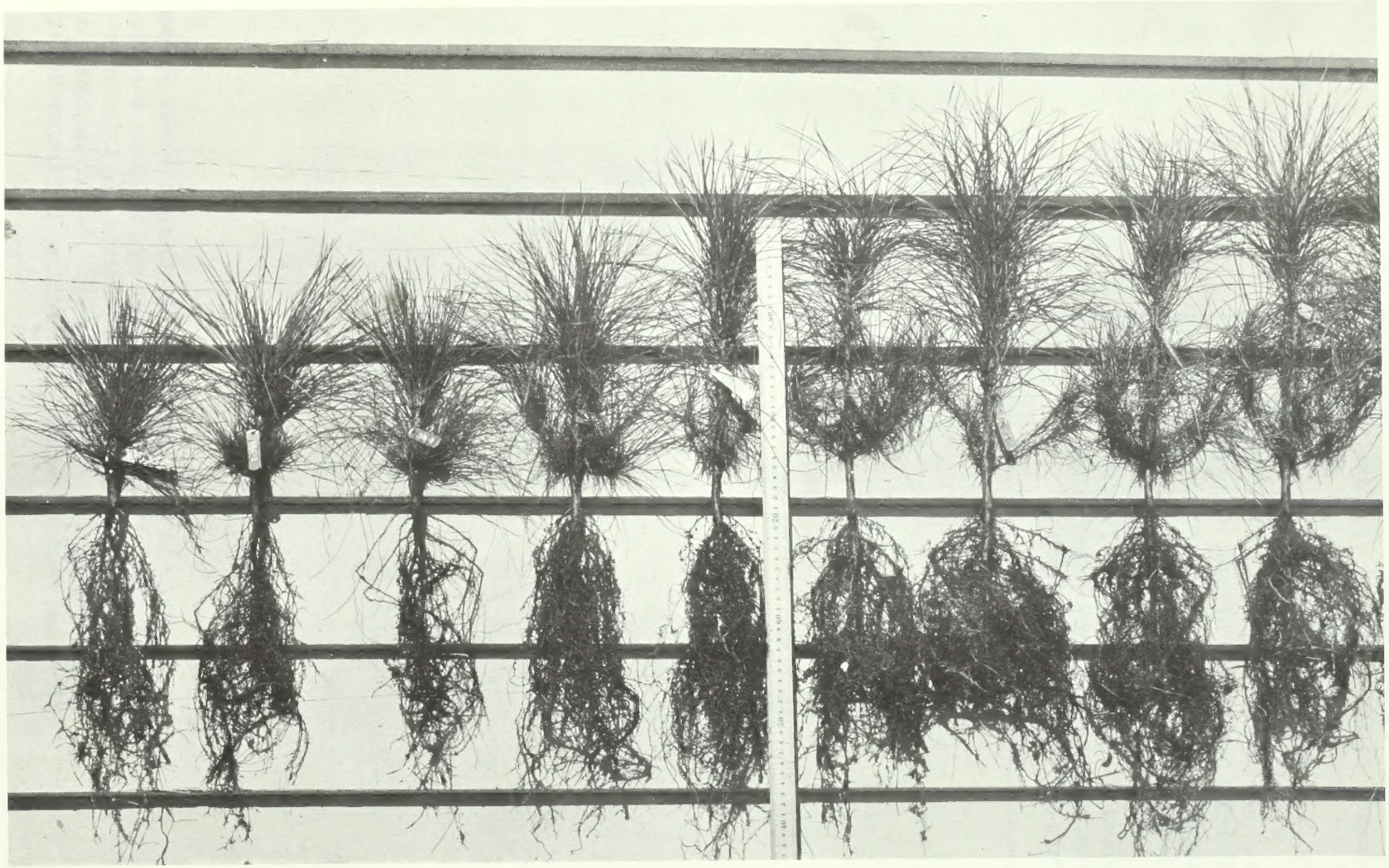
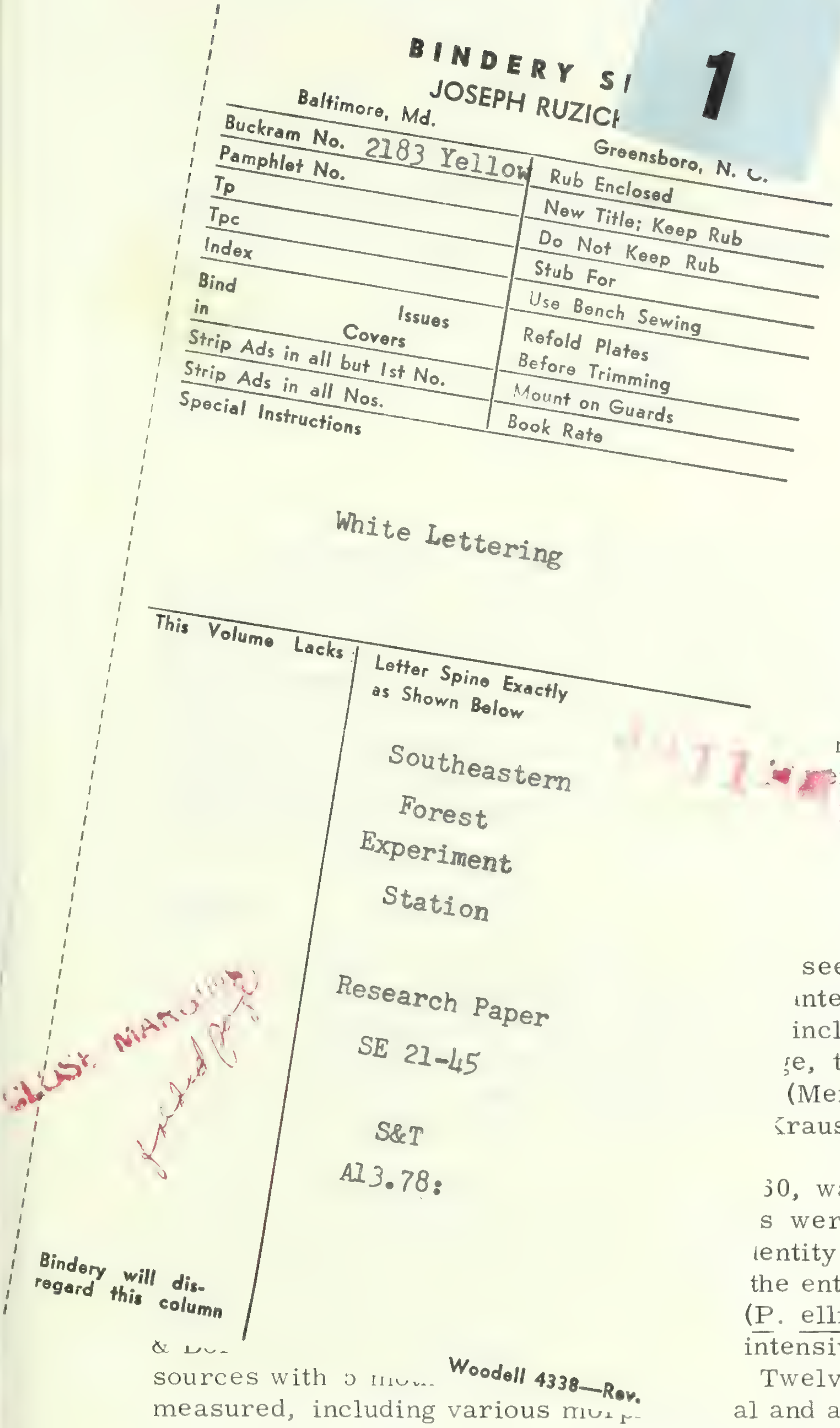
The author is Principal Plant Geneticist, Naval Stores and Timber Production Laboratory, Olustee, Florida. This Research Paper was presented at the 132nd meeting of the American Association for the Advancement of Science, held at Berkeley, California, December 26-31, 1965.



One-year-old slash pine seedlings grown in the 1960 experiment from seeds collected along a transect extending from the southern tip of Florida (left) to central Georgia (right).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S AFFECTED

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ents in slash pine (Pinus
patterns found with cli-

seeds were collected from
inted at 7 localities. Meas-
included germination, sur-
ge, tree height, damage by
(Mergen and Hoekstra 1954;
Kraus 1959; and Bengtson[1]).

30, was similar but had sev-
s were measured as well as
lentity was maintained through-
the entire range of slash pine,
(P. elliottii var. densa Little
& Do... intensive, there being 54 seed
sources with 5 mo... Twelve parental traits were
measured, including various mor... al and anatomical characteristics in cones, seeds, and foliage. Progenies were studied through their first year only; germination and early growth rate were measured along with foliar characters (Squillace 1966).

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[1] Bengtson, G. W. Phenology of terminal growth in slash pine; some differences related to geographic seed source. (In press.)

Patterns of Variation

Most of the traits, both parental and progeny, showed significant differences among sources. The patterns of variation differed among traits but most were characterized by gradients between high and low areas. These "highs" or "lows" frequently occurred at the northern or southern limits of the species range but were also found in interior areas, especially in extreme south Georgia and north Florida (north-central region). In many traits the patterns were distinct, while in some they were highly irregular or entirely random. In a few, the variation was clinal in one portion of the species range and random in another. Patterns for a few of the traits are illustrated in figures 1 to 3.

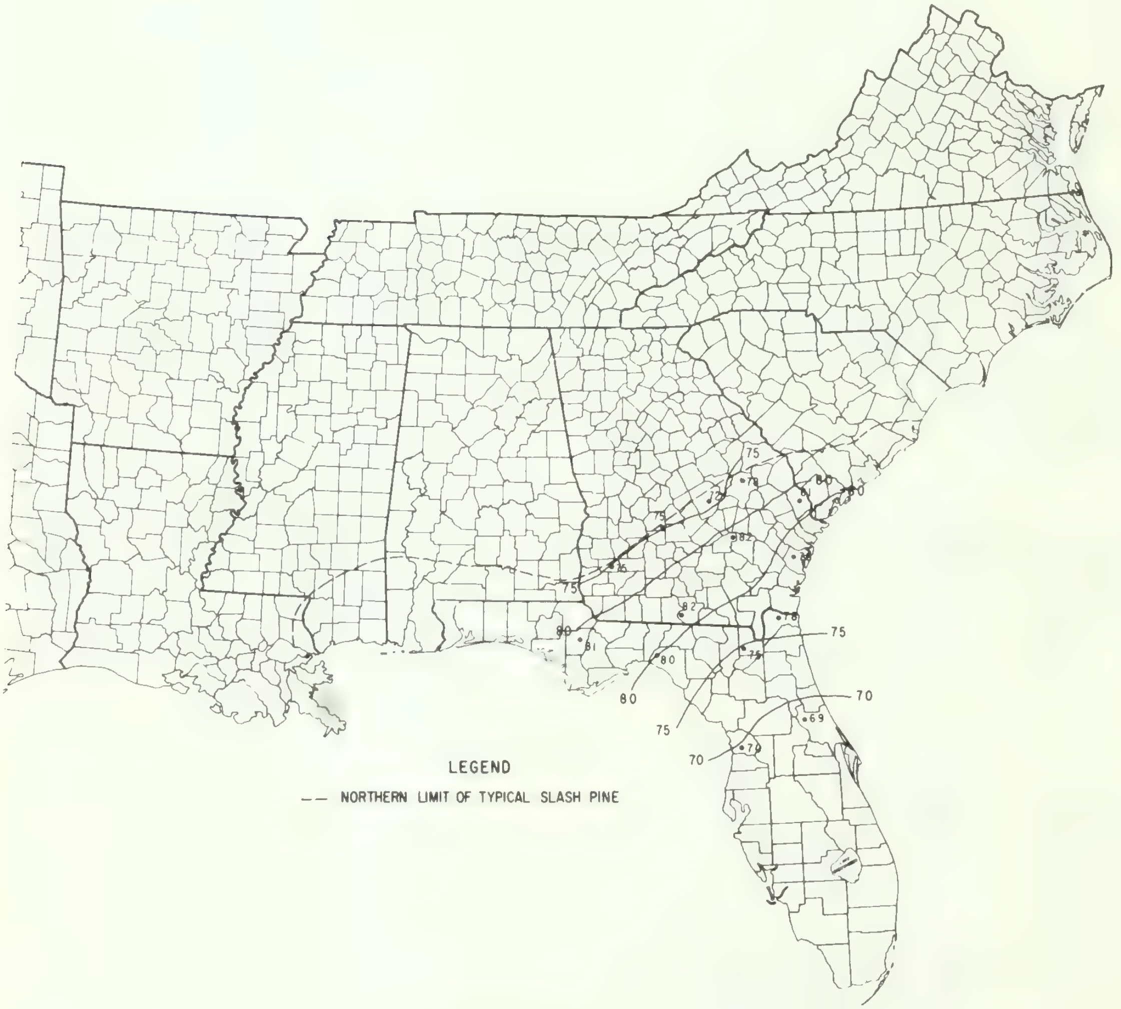

Figure 1.--Average total heights over all plantations, 5 years after outplanting, in the 1953 experiment (feet). The dots in the map indicate stand location, and the numbers are seedling heights.

Figure 1 shows average total heights in the 1953 experiment 5 years after outplanting. Note the ridge, running northeast-southwest through south Georgia and north Florida. Heights decrease to the north and to the south of the ridge.

Most patterns were not so simple. Figure 2 shows the average number of cotyledons per seedling in progenies of the 1960 experiment. Note the definite "low" in southeast Georgia, encircled by a ridge. Beyond the ridge, cotyledon number decreased to the extreme west and south ends of the species range.

Figure 3, showing seed yield per cone in parents of the 1960 experiment, is an example of an irregular pattern. Note the ridge extending from Louisiana eastward to southeast Georgia. Seed yields tended to be lower to the north and south of the ridge.

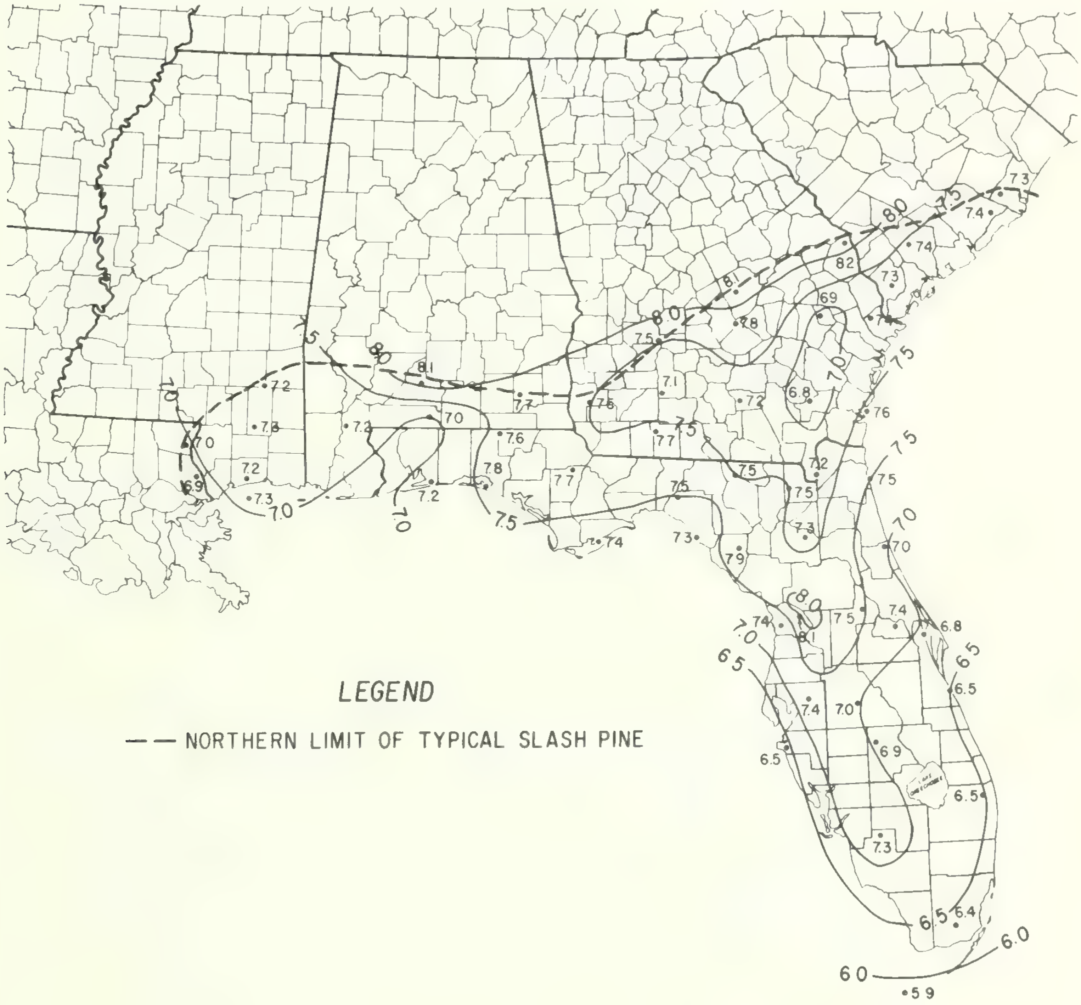

Figure 2.--Cotyledon number in progenies of the 1960 experiment. The dots in the map indicate stand location.

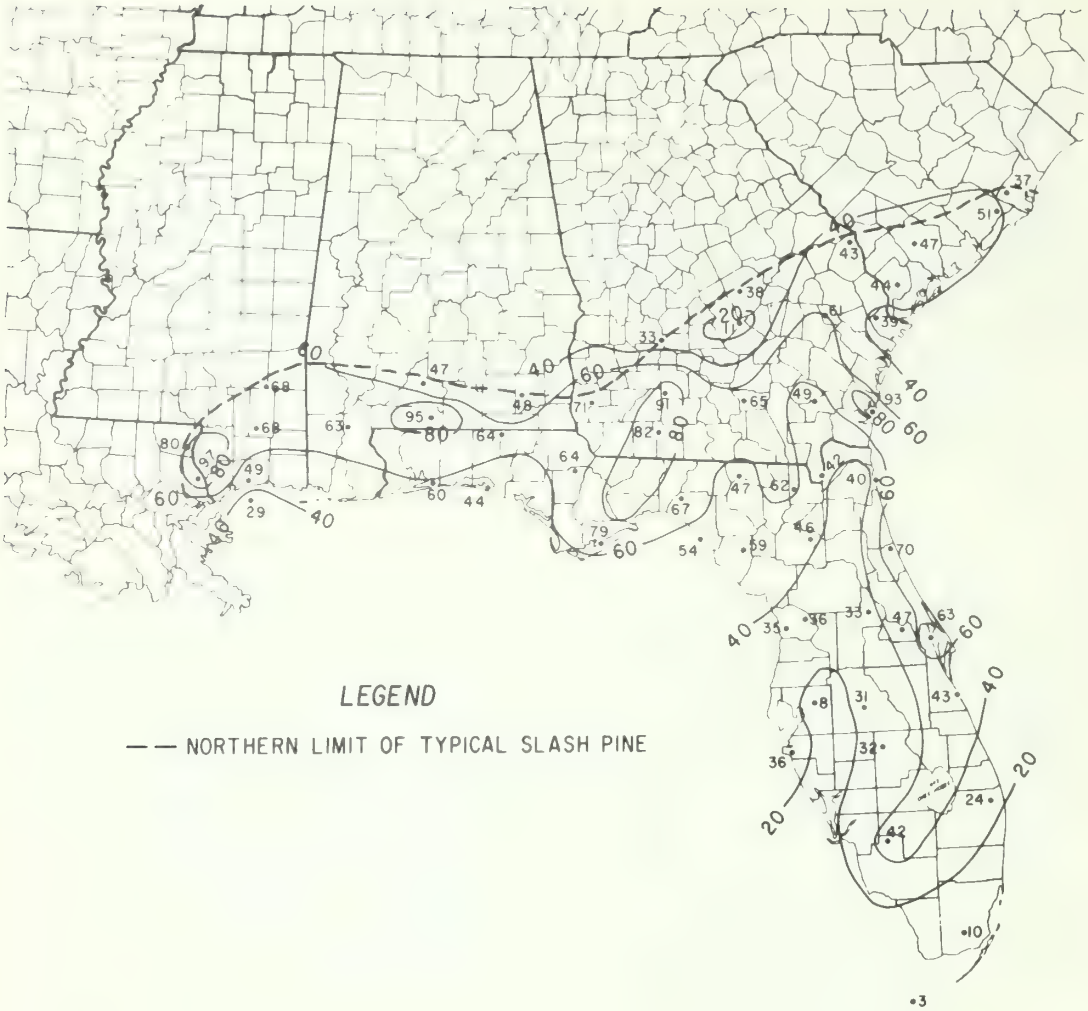

Figure 3.--Sound seed yield per cone in parent trees of the 1960 experiment. The dots in the map indicate stand location, and the numbers are seeds.

Relations to Climate

The results suggest that climate had a strong influence on most of the variation patterns. The main reason for this belief is that, as with most of the trait patterns, the significant climatic features vary continuously over the species range. For example, mean January temperatures increase gradually from north to south (fig. 4). Difference between maximum and minimum daily temperatures are low along the coast and increase with increasing distance from the coast (fig. 4). Early-season rainfall (January to April) increases from south to north and northwest (fig. 5). Late-season rainfall (June to September) increases in a direction opposite to that of early-season rain (fig. 5).

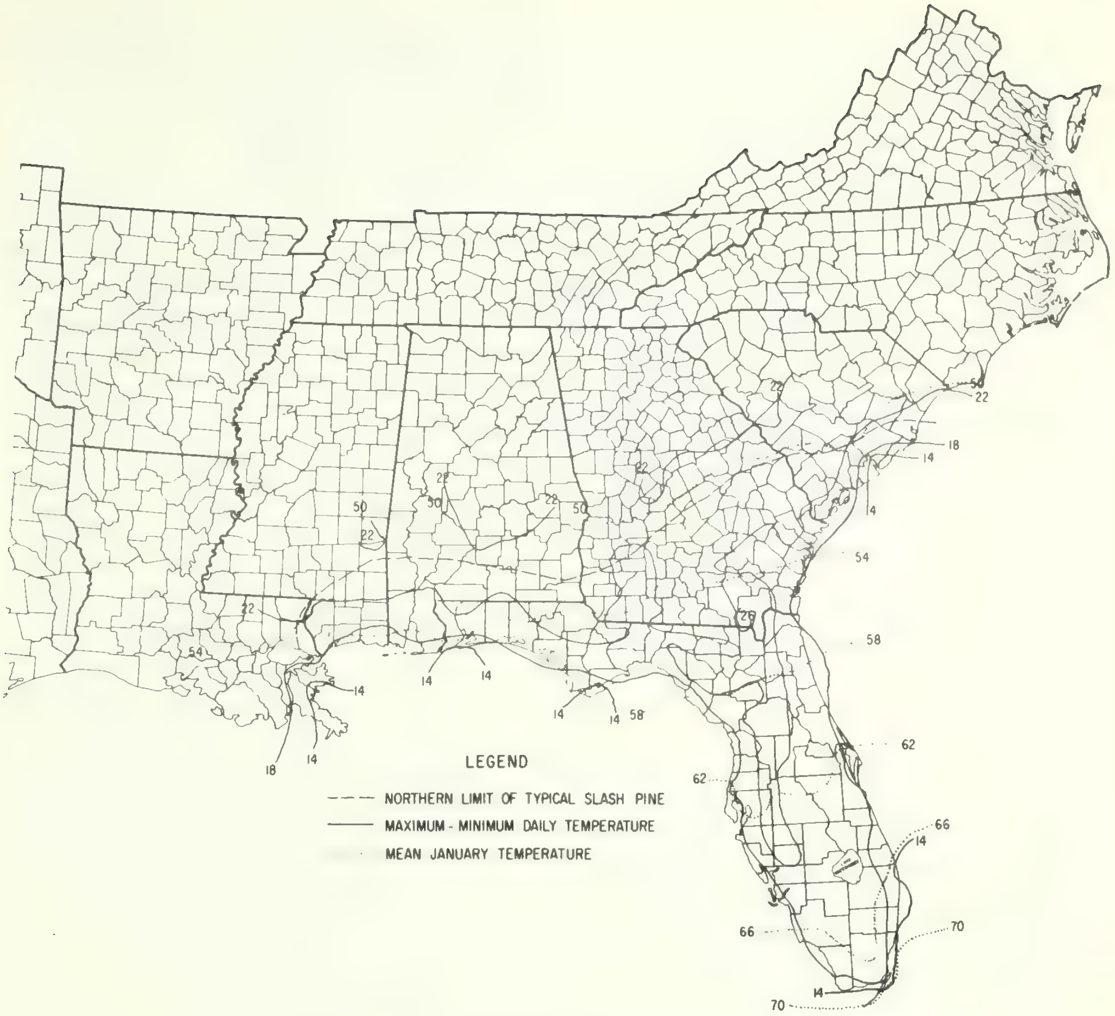

Figure 4.--Mean January temperature (°F.) and the average difference between mean maximum and mean minimum daily temperature during April through September (°F.). The former are based on data for 1931 to 1955 (U. S. Weather Bureau 1959), while the latter are based on data for 1931 to 1952 (U. S. Weather Bureau 1956).

These gradients in climatic factors probably caused the continuous nature of the trait patterns. Climate affects the phenotypic expression of many traits, adapting the trees to their native habitat. Climate also acts as a selection agent in causing genetic variation in traits that are important in fitness, such as speed of germination, growth rate, and others. Some traits, such as needle length and number of needles per fascicle, may not be important fitness characters, but genetic variation in them could have resulted from association with fitness characters, such as through pleiotropy (common genes).

The trend reversals (highs or lows in interior areas) that were frequently found could have been due to combinations of two or more climatic factors having interacting or curvilinear effects. For example, the trend reversal for growth rate in the north-central region may be due to the combined effects of winter temperature and early-season rainfall. Growth rate may increase with increasing winter temperature and with increasing early-season rainfall up to threshold values. Thus, low winter temperatures in the north and low early-season rainfall in the south would be limiting factors. Such a situation would cause maximum growth at some point between the northern and southern limits of the species range.

Although emphasis has been on climate in explaining the patterns of variation, other environmental factors such as soil and topographic features undoubtedly had some effects. These, like climatic factors, could cause adaptive modifications as well as genetic differences. Soil and topographic features could have caused some of the sharp breaks that were present in some patterns.

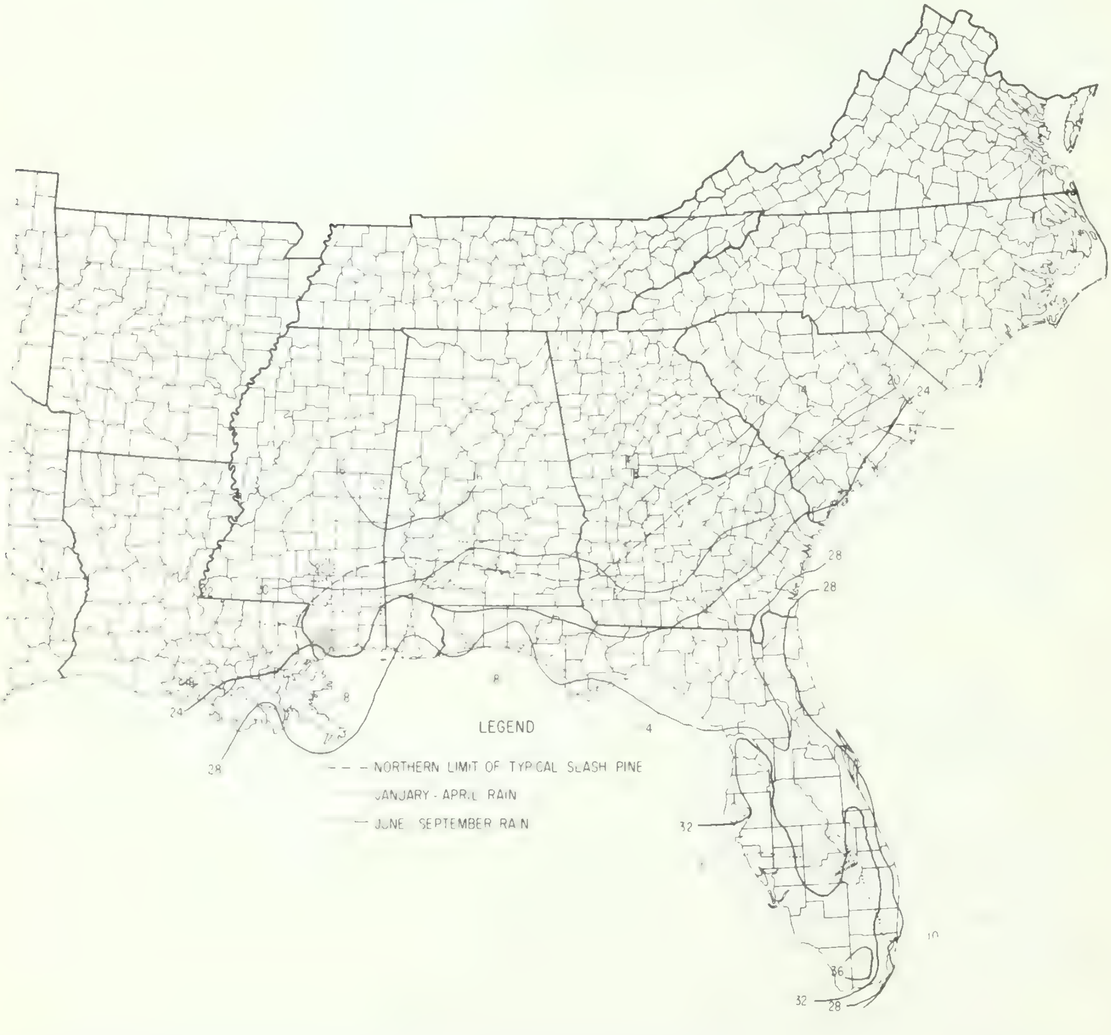

Figure 5.--Precipitation from January through April (inches) and June through September (inches). Based on data for 1931 to 1955 (U. S. Weather Bureau 1959).

Finally, we must consider other mechanisms such as genetic drift and introgressive hybridization as factors affecting the patterns. At an early stage of the Pleistocene Period, peninsular Florida was reduced to a group of small islands, some of which were rather isolated. Ecotypes could have evolved on some of these islands. Subsequent migration and introgressive hybridization between ecotypes could then explain the existence of gradients and the trend reversals in peninsular Florida. However, this would not explain the gradients and trend reversals in the northern areas. Thus, it is concluded that climate was a predominant factor in evolution of the patterns, although other factors may also have been involved.

Squillace and Kraus (1959) hypothesized that climate is optimum for growth of slash pine in the north-central region. They noted that in the area of most rapid growth early-season rainfall varied from 14 to 18 inches, late-season rainfall varied from 21 to 28 inches, and length of growing season was more than 250 days. An attempt is made here to delineate the apparent optimum region, using arbitrarily designated minimum values for four climatic factors: early-season rainfall, late-season rainfall, mean January temperature, and the average difference between mean maximum and mean minimum daily temperature during April through September (a measure of coastal influence).

Isograms were drawn for the minimum values of the four factors in figure 6. The areas bounded by them, shaded in the figure, are presumed to be most suitable climatically for growth of slash pine. Note the longitudinal extension of this presumed optimum[2] zone. It corresponds to the fact that longitudinal variation in most tree characteristics, notably growth rate, was usually smaller than latitudinal variation. Although the delineation is highly arbitrary, it is based upon our best knowledge of phenotypic and genetic differences in growth and of influences of environment.

In considering this zone we must keep in mind the continuous nature of climatic factors. Suitability of climate is believed to be greatest in the area delineated but it decreases progressively away from the area toward limits of the species range.

Squillace and Kraus (1959) explained the genetic superiority of growth rate in the north-central region through effects of natural selection. In this area, where climate is presumably optimum, growth rate takes on a relatively important role in natural selection, in comparison to other traits. At areas removed from this zone, other traits become progressively more important. For example, at the extreme northern limits of the species range natural selection strongly favors such traits as resistance to cold temperatures and ice damage, and it does so at the expense of growth rate. To the south, genetic adaptation to droughty winters, summer floods, and possibly frequent fires becomes more important than growth rate. Genetic adaptation to these and other critical factors occurring along the Florida coasts, such as brackish soil water, salty air, frequent tropical storms, and poor soil drainage, may indeed be the cause of the relatively slow growth of south Florida slash pine. Low day-night temperature differentials along coastal areas may also have been instrumental (Kramer 1957), although it is difficult to visualize this factor as a selection agent.

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[2] By "optimum" here is meant the most suitable climate for slash pine within the species range. More suitable climates may occur in areas out of the species natural range. Likewise, artificially created environments are not considered here.

The hypothesis may be summarized as follows. Within the range of slash pine there is an area where environmental factors are most favorable for growth of slash pine. In this area native trees are both phenotypically and genetically superior in growth rate. Away from this area, toward areas of less favorable environment, the trees are progressively slower-growing.

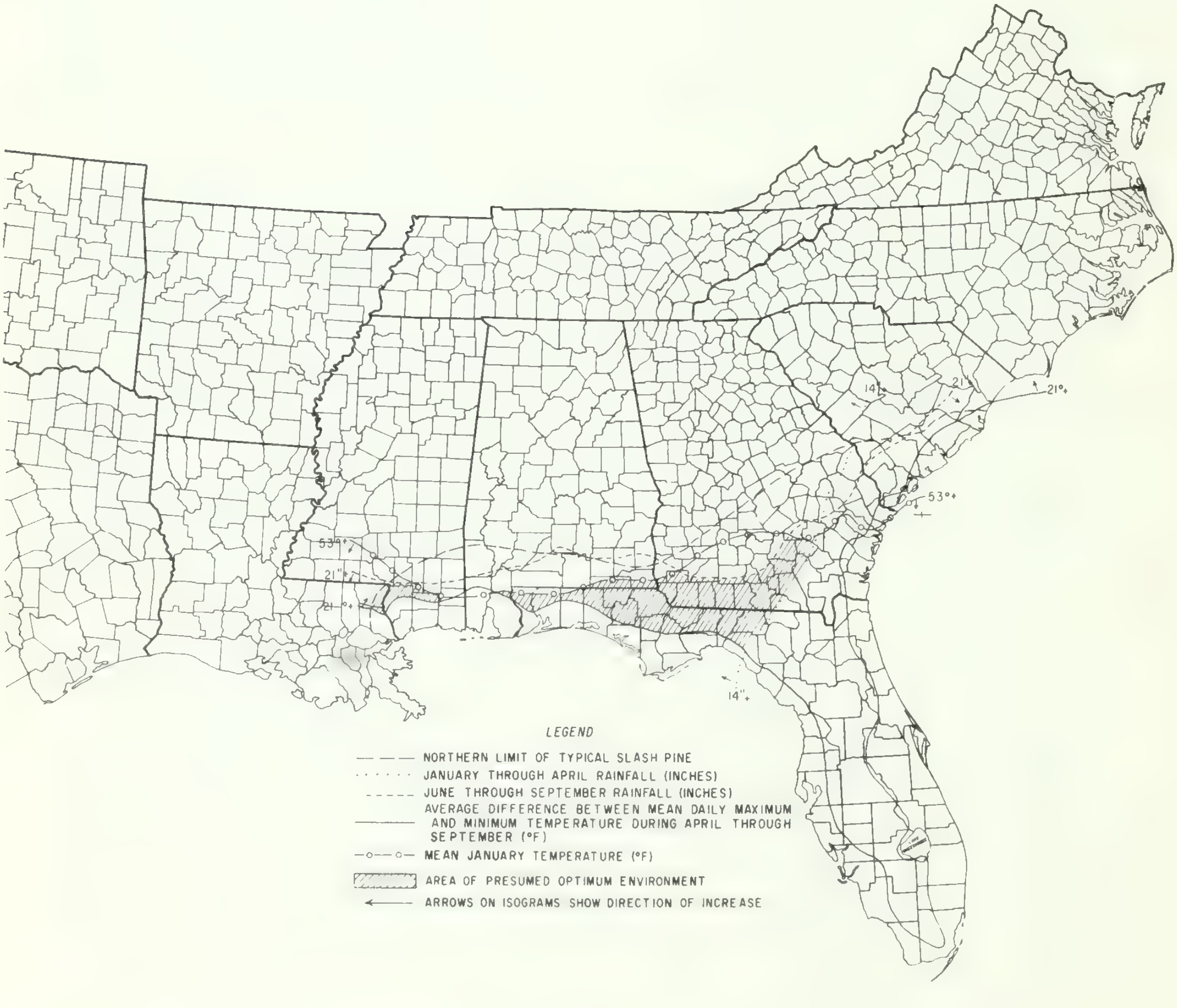
14"
21"
21°
53°
53°
21"
21°
14"
LEGEND
NORTHERN LIMIT OF TYPICAL SLASH PINE
JANUARY THROUGH APRIL RAINFALL (INCHES)
JUNE THROUGH SEPTEMBER RAINFALL (INCHES)
AVERAGE DIFFERENCE BETWEEN MEAN DAILY MAXIMUM AND MINIMUM TEMPERATURE DURING APRIL THROUGH SEPTEMBER (°F)
MEAN JANUARY TEMPERATURE (°F)
AREA OF PRESUMED OPTIMUM ENVIRONMENT
ARROWS ON ISOGRAMS SHOW DIRECTION OF INCREASE

Figure 6.--Delineation of the presumed optimum region for growth rate in slash pine.

From a practical standpoint we must remember, however, that trees are generally most adaptive in their native habitats. Thus, if one collects seed from the presumed optimum zone and plants it elsewhere to obtain superior growth, he runs the risk of maladaptation. In slash pine, fortunately, studies to date suggest that trees from the northern portion of the species range can be moved practically anywhere within the species range, with little loss in survival over native stock. Moving seeds from south to north entails more risk but this is not commonly done, because of inherent slow growth of south Florida trees. Movement of seed from coastal to interior areas likewise may not be desirable.

The hypothesis of inherently superior growth in areas of optimum environment may apply to other tree species. Evidences favoring it seem to be present in studies of ponderosa pine (*P. ponderosa* Laws.) (Squillace and Silen 1962), eastern white pine (*P. strobus* L.) (Funk 1964), longleaf pine (*P. palustris* Mill.) (Shoulders 1965), and possibly others.

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U. S. Forest Service Research Paper SE-22

June 1966

FOREST TREE IMPROVEMENT RESEARCH IN THE SOUTH AND SOUTHEAST

by

Keith W. Dorman

Sponsored Publication No. 26 of the Committee
on Southern Forest Tree Improvement

U. S. DEPARTMENT OF AGRICULTURE—FOREST SERVICE
Southeastern Forest Experiment Station
Asheville, North Carolina

This summary of forest tree improvement and forest genetics research projects in the southern pine region informs research workers and other interested people about work under way and where it is being done. The survey also strengthens and coordinates such research. The U. S. Forest Service is glad to foster the work of the Committee on Southern Forest Tree Improvement by publishing this report.

T. F. McLINTOCK, DIRECTOR
Southeastern Forest Experiment Station

Foreword

The Committee on Southern Forest Tree Improvement has directed its Subcommittee on Tree Selection and Breeding to summarize the projects by agencies doing forest tree improvement research in the South and Southeast. This area corresponds roughly to what is known as the southern pine region. The project summaries and the consolidated report were to be patterned after those issued from the Lake States and from the Western states including British Columbia, Canada.

The Southern and Southeastern report describes 305 research projects being conducted by 36 research agencies at various locations. The survey gives reasonably good coverage of present forest tree improvement research in the area. The report is presented for the consideration of those conducting or supporting forest tree improvement and forest genetics research, and for others interested in the broad forestry research program that is developing in the South and Southeast.

Any survey of research in an active field of work is somewhat out of date by the time it is printed. However, studies that are costly and run for many years do not change quickly, and it is these that should not be duplicated. It is hoped that the survey of current work will help researchers to avoid such duplication.

Often there is no sharp distinction between tree improvement or forest genetics studies and certain other fields of forestry. The only logical basis for classifying many studies is their basic purpose. For example, seed orchard culture is an important general subject of interest to many people. Yet individual studies are appropriately classified under basic subjects such as variation and inheritance of flower production, flower induction, nutritional studies, tree spacing studies, vegetative propagation, pollen flight, tree crown shaping, cone or seed insect control, cone or seed disease control, and others relating to growing trees or managing areas of trees for seed production. Classification of studies by the basic subject or subjects covered has made extensive cross referencing unnecessary.

Each statement shows the scientific names of the tree species, or the group, such as hardwood or softwood. Occasionally the word "General" is used instead of the species name to indicate broad projects applying to many genera.

Work under the Regional Project, "Forest Tree Genetics, S-23," of the State Agricultural Experiment Stations is indicated for some studies under the college or university of the State involved. The following State experiment stations cooperate at present in this project: Alabama, Mississippi, Louisiana, Tennessee, Texas, Georgia, Florida, North and South Carolina.

No attempt has been made to report all seed orchards and seed production areas established by all agencies. This activity was the object of a special survey by the U. S. Forest Service, and acreage figures were published in Tree Planters' Notes No. 74, December 1965. However, some agencies have included seed orchards in their survey reports because of the research aspects, or for other reasons.

This report supersedes one published in 1952, "Directory of forest genetic activities in the South," Southeastern Forest Experiment Station, Station Paper No. 17.

The Subcommittee on Tree Selection and Breeding gratefully acknowledges the assistance of research agencies and workers who generously gave their time in preparing the project statements, the men who assembled the report by States, and the Forest Genetics Research Foundation, which stimulated this work and set a pattern for the report.

KEITH W. DORMAN, CHAIRMAN
Subcommittee on Tree Selection and Breeding

AGENCIES CONDUCTING RESEARCH

Code Number	Name		Number of Projects Reported
1	Auburn University		8
2	Buckeye Cellulose Corporation		1
3	Clemson University		8
4	Continental Can Company		10
5	Florida Forest Service		3
6	Florida Forests Foundation		3
7	Ida Cason Callaway Foundation		2
8	International Paper Company		4
9	Louisiana State University		2
10	North Carolina State University		11
11	Tennessee Valley Authority		4
12	Texas Forest Service		10
13	Union Bag-Camp Paper Corporation		8
14	United States Forest Service, Forest Products Laboratory		1
15	United States Forest Service, Region 8		1
	United States Forest Service, Southeastern Forest Experiment Station		88
16	Asheville, North Carolina	11	
17	Athens, Georgia	8	
18	Blacksburg, Virginia	5	
19	Charleston, South Carolina	10	
20	Cordele, Georgia	3	
21	Fort Myers, Florida	2	
22	Franklin, Virginia	1	
23	Macon, Georgia	14	
24	Marianna, Florida	6	
25	Olustee, Florida	28	
	United States Forest Service, Southern Forest Experiment Station		98
26	Alexandria, Louisiana	7	
27	Crossett, Arkansas	17	
28	Gulfport, Mississippi	53	
29	Harrison, Arkansas	4	
30	Stoneville, Mississippi	17	
31	University of Florida		6
32	University of Georgia		11
33	University of Tennessee		14
34	University of Virginia		1
35	Virginia Division of Forestry		1
36	West Virginia Pulp and Paper Corporation		10
		Total	305

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Forest Tree Improvement Research in the South and Southeast

A Survey

by the Committee on Southern Forest Tree Improvement

by

Keith W. Dorman, Principal Silviculturist
Southeastern Forest Experiment Station
Forest Service, U. S. Department of Agriculture

THE PATTERN OF THE PROJECT DESCRIPTIONS

In the following pages, each person in charge of the work describes his current forest tree improvement research project in the South and Southeast in a brief statement consisting of the title, description of the objectives and methods, a list of cooperators (if any), and the names of those responsible for the study.

Each statement is preceded by a hyphenated reference number for identification of the project in cross references and the indexes; the first number identifies the research agency, and the second the project under that agency. Following the title are classification numbers showing the subject-matter category of the project. These categories are listed on page 84 in accordance with a classification systems prepared by Dr. Scott S. Pauley.

To insure that pertinent material is seen, the reader should study the subject-matter classification outline before attempting to review various topics.

RESEARCH PROJECTS

1. AUBURN UNIVERSITY, DEPARTMENT OF FORESTRY

Auburn, Alabama

1—1. Variation in *Cupressus*. 111.0, 111.1, 111.3. *Cupressus arizonica, Cupressus* spp.

OBJECT: (1) Investigate phenotypic variation in species of *Cupressus* native to the United States, and (2) determine genetic variation in *Cupressus arizonica*.

METHODS: Collect seed from and study all species in their native habitats. Seed is kept separate by mother tree to establish one open-pollinated progeny test planting of approximately 10 acres. Provenance test plantings of all species will be established in different regions of Alabama.

ASSIGNMENT: James F. Goggans, Associate Professor.

1—2. Trials of exotic species. 111.0, 211.0. Softwood and hardwoods.

OBJECT: Evaluate promising exotics as replacements for currently grown species and establish these exotics as a source of breeding material.

METHODS: Introduce trees not native to the area. Establish in plots and evaluate in terms of growth, form, wood quality, insect and disease resistance, and tolerance to climate.

ASSIGNMENT: James F. Goggans, Associate Professor.

1—3. Variability within forest tree species. 111.1, 111.2, 111.3, 211.1, 211.2, 211.3. *Pinus taeda, P. virginiana, Liquidambar styraciflua,* and others to be selected.

OBJECT: (1) Determine phenotypic variation in selected characteristics within and among races of major forest tree species in Alabama and surrounding areas, and (2) determine variation within and among progenies of races and selected individuals from Alabama and surrounding areas.

METHODS: Select sample trees within stands, sites, and physiographic regions. Measure growth, form, and wood characteristics. Analyze to estimate phenotypic variation within stands, between stands, and between regions. Collect seed from sample trees, selected as above, and plant seedlings in designed plantings on varying sites. As part of these studies a *Pinus taeda* provenance study was established 5 years ago. It involves eight seed sources in Alabama with plantings near each source. Phenotypic variation in growth and wood characteristics of *Liquidambar styraciflua* is also being investigated. Eighty-five 5-tree plots have been established throughout Alabama. Wood characteristics being studied are percent heartwood, specific gravity, and fiber length.

ASSIGNMENT: James F. Goggans, Associate Professor.

1—4. WOOD CELL ANATOMY. 111.3, 151.321, 151.322, 211.3, 251.321, 251.322, 251.324. *Pinus taeda, Liquidambar styraciflua.*

OBJECT: (1) Determine a practical, accurate method of measuring cell diameters and wall thicknesses; (2) determine the within-tree variation in cell diameter, wall thickness and length, and devise a method of sampling these characteristics; and (3) determine the degree of correlation between cell dimensions, specific gravity, percentage of summerwood, and rate of growth.

METHODS: Compare precision of cell diameter and wall thickness measurements made on macerated and solid wood samples under various combinations of transmitted and reflected normal and polarized light and fluorescence. Measure total variation with annual ring. Try sampling schemes to estimate means and variation. Use best scheme to measure variation along several radii at breast height. Extend sampling scheme to devise method for sampling cell dimensions in bole. Measure specific gravity, percentage summerwood, and rate of growth. Use correlation techniques to investigate relations between these characteristics and cell dimensions.

ASSIGNMENT: James F. Goggans, Associate Professor.

1—5. HYBRIDIZATION. 112.01, 112.02. *Pinus* spp.

OBJECT: Develop hybrid forest trees for problem sites such as the dry, shallow-soiled sites found in the southern Appalachians.

METHOD: Cross within and between species parent trees selected for improved wood quality, insect and disease resistance, and ability to grow on the problem site involved.

ASSIGNMENT: James F. Goggans, Associate Professor.

1—6. DEVELOPMENT OF IMPROVED CYPRESS CHRISTMAS TREES. 122.1. *Cupressus arizonica.*

OBJECT: Develop an improved synthetic variety of *Cupressus arizonica* for use as a Christmas tree.

METHODS: Collect seed from native habitats in the southwestern U. S. and grow trees in various regions of Alabama. Select outstanding trees from these plantings and transfer by vegetative propagation to seed orchards. Recurrent selection procedures will be used in developing the improved variety.

ASSIGNMENT: James F. Goggans, Associate Professor.

1—7. DEVELOPMENT OF IMPROVED TREES. 122.1. *Pinus taeda, P. palustris, P. elliottii, P. virginiana, P. echinata.*

OBJECT: Develop improved synthetic varieties of forest trees.

METHODS: Use selection procedures combined with seed orchards to develop synthetic varieties.

COOPERATOR: Alabama Department of Conservation, Division of Forestry.

ASSIGNMENT: James F. Goggans, Associate Professor.

1—8. ROOTING STUDIES. 151.02, 251.02. *Cupressus arizonica, Pinus virginiana, Liquidambar styraciflua.*

OBJECT: Develop and try techniques of rooting forest tree species in order to make the production of large quantities of asexually reproduced trees easier.

METHODS: Try Arizona cypress rooting techniques developed by the Horticulture Department of the Arkansas Agricultural Experiment Station. Try these techniques on Virginia pine also. The above developed techniques involve initial treatment with 20 ppm IBA solution, and after 45 days, rewounding and treatment with 500 ppm IBA or NAA solution Other root inducing substances will be tried also. Methods developed by the Horticulture Department of the Alabama Agricultural Experiment Station will be tried on all three listed species. These methods involve treatment with material extracted from germinating chestnut seeds or placing the cutting directly in a germinating chestnut seed.

ASSIGNMENT: James F. Goggans, Associate Professor.

2. BUCKEYE CELLULOSE CORPORATION

Perry, Florida

2—1. Slash pine racial variation. 111.1. *Pinus elliottii.*

OBJECT: To investigate the existence of a Gulf coastal race of slash pine.

METHODS: Reciprocal plantings were made on coastal and inland sites during 1959-60 planting season. Open-pollinated seedlings grown from typical inland and coastal forms were planted in completely randomized experimental designs—single-tree plots, 10- x 10-foot spacing. Crown shape was selection basis for source trees. Anatomical features of needles, i.e., resin ducts, marginal teeth, number and size of stomates, etc., to be used for initial separation of ecotypes. Crosses of source trees in both directions are planned. Coastal outplanting: Sec. 22 of T9S, R9E, Taylor County, Florida. Inland outplanting: Sec. 9 of T5S, R7E, Taylor County, Florida.

ASSIGNMENT: Walter L. Beers, Jr., Research Forester.

3. CLEMSON UNIVERSITY, DEPARTMENT OF FORESTRY

Clemson, South Carolina

3—1. Seed source study in eastern redcedar. 111.1. *Juniperus virginiana.*

OBJECT: To locate and propagate strains of eastern redcedar suitable for Christmas trees in South Carolina.

METHODS: Two hundred seedlings are being obtained from each of 24 states, mostly from state nurseries. These will be grown in a South Carolina state nursery for one year to minimize original nursery effects, and then will be outplanted on the Clemson Forest.

COOPERATOR: South Carolina Commission of Forestry.

ASSIGNMENT: R. E. Schoenike, Associate Professor.

3—2. Variation in longleaf pine. 111.1, 111.2, 111.3. *Pinus palustris.*

OBJECT: To study variation in longleaf in South Carolina.

METHODS: Cones have been collected from 5 trees in each of the 34 counties in South Carolina where the species occur. These will be grown in a South Carolina nursery and outplanted on a coastal plain and a sandhills site.

COOPERATORS: South Carolina Commission of Forestry; Atomic Energy Commission, Savannah River Project.

ASSIGNMENT: R. E. Schoenike, Associate Professor.

3—3. Variation in Virginia pine. 111.3. *Pinus virginiana.*

OBJECT: To ascertain the variation among the progeny of individual trees growing in South Carolina.

METHODS: Seed has been collected from 65 trees located in 10 counties of the upper Piedmont, S. C. Seedlings were outplanted in January 1965 on the Clemson Forest. A 10-

tree randomized row plot was used. Number of replications varied from 3 to 10 depending on the supply of seedlings.

COOPERATOR: South Carolina Commission of Forestry.

ASSIGNMENT: R. E. Schoenike, Associate Professor.

3—4. SUPERIOR TREE SELECTION IN LOBLOLLY PINE. 111.3, 112.02. *Pinus taeda.*

OBJECT: To locate superior trees and use these in breeding studies.

METHODS: Approximately 2,300 acres of 25- to 30-year-old plantations of loblolly pine on the Clemson Forest are being systematically searched for superior trees. Selected trees will be evaluated by standard methods. The trees will later be used in developing an experimental seed orchard for carrying on breeding studies.

COOPERATOR: Management staff of the Clemson Forest.

ASSIGNMENT: R. E. Schoenike, Associate Professor.

3—5. SEED PRODUCTION AREA IN LOBLOLLY PINE. 122.0. *Pinus taeda.*

OBJECT: To develop an area for temporary seed production, demonstration, and educational purposes.

METHODS: A 10-acre, 30-year-old planted stand has been rogued of undesirable trees and thinned to leave the best 40 trees per acre. A second cut next year will reduce the stand to 25 trees per acre. The central 2 acres will be the seed production proper. First seed collections will be made in fall 1966. These will partially meet the needs of management objectives of the Clemson Forest until improved seed from seed orchards become available.

COOPERATOR: Management staff, Department of Forestry, Clemson University.

ASSIGNMENT: R. E. Schoenike, Associate Professor; A. T. Shearin, Assistant Forester.

3—6. INBREEDING IN VIRGINIA PINE. 112.03, 141. *Pinus virginiana.*

OBJECT: To determine the effect of selfing.

METHODS: Twenty-five trees on the Clemson Forest were selfed in 1963. A repeat was made in 1964. Observations will be made on nursery bed seedlings and on outplantings.

ASSIGNMENT: R. E. Schoenike, Associate Professor.

3—7. X-RAY EXAMINATION OF SEED EMBRYOS. 151.3, 251.3. *Pinus palustris, P. elliottii, P. taeda, P. echinata, Juniperus virginiana, Fraxinus* spp., *Liquidambar styraciflua, Nyssa sylvatica,* and *Liriodendron tulipifera.*

OBJECT: (1) Attempt to obtain clear X-ray pictures of seed embryos within the intact seed, and (2) attempt to correlate embryo conditions determined from such pictures with seed viability as determined from actual germination tests or other tests.

METHODS: Seed samples are photographed with a low-voltage industrial X-ray machine using Type M film. The same seed are then tested by other methods to determine whether X-ray examination can replace or supplement conventional testing methods.

COOPERATOR: U. S. Atomic Energy Commission, Savannah River Operations.

ASSIGNMENT: W. H. Davis McGregor, Associate Professor.

3—8. VARIATION IN *Quercus* SPP. 211.1, 211.3. *Quercus falcata.*

OBJECT: To study individual tree and racial variation in selected species of *Quercus,* beginning with *Quercus falcata.*

METHODS: Acorns will be collected from 5 trees in each of about 40 localities throughout the range of southern red oak. Material will be grown in a South Carolina nursery and outplanted in the Piedmont and coastal plain areas of the state.

COOPERATOR: S-23 Project members; South Carolina Commission of Forestry.

ASSIGNMENT: R. E. Schoenike, Associate Professor.

4. CONTINENTAL CAN COMPANY, INC.

Savannah, Georgia

4—1. TRIALS OF SOME MEXICAN PINE SPECIES. 111.0. *Pinus.*

OBJECT: To compare the performance of some of the Mexican pine species with slash and loblolly pine.

METHODS: Species under test include *Pinus montezumae, P. rudis, P. Hartweggii, P. oocarpa, P. michoacana, P. Lawsoni, P. tenuifolia, P. Douglasiana, P. teocote, P. patula, P. durangensis, P. pseudostrobus, P. leiophylla, P. Herrerai, P. arizonica, P. chihuahuana,* and slash and loblolly pine. Test plantings have been established in Florida, Georgia, and Virginia; 15-tree plots, 4-6 replications. Additional plantings are planned (initial survival was poor). This seed was collected in 1963 by the Cooperative Industry-North Carolina State College Group; wood samples, botanical specimens, and mensurational data were collected at the same time.

COOPERATORS: Kimberly-Clark Corp.; Bowaters Inc.; Union Bag-Camp Corp.; Champion Paper Co.; West Virginia Pulp & Paper Co.; and North Carolina State University.

ASSIGNMENT: D. E. Cole, Research Forester

4—2. WOOD PROPERTIES OF SLASH, LOBLOLLY, AND LONGLEAF PINE IN NORTHEAST FLORIDA, EASTERN GEORGIA, AND SOUTHEASTERN SOUTH CAROLINA. 111.0, 111.1, 111.3, 151.32. *Pinus elliottii, P. taeda, P. palustris.*

OBJECT: (1) To determine the wood properties of these species as they vary with site, age, geographic area, species, between natural stands and plantations, etc., and (2) to locate trees with outstanding wood properties for future use.

METHODS: Twenty-tree plots of dominants and codominants only; 50 slash plots, 30 plots each of loblolly and longleaf are planned. Four site classes, four age classes, three geographic areas, and two plots in each condition class are used. Two trees per plot (random selections) are felled, weighed bolt by bolt, and each bolt sampled with 10mm. cores and wedges; 2 trees per plot are sampled with two 10mm. breast height cores; and the other 16 trees sampled with a single 10mm. breast height core. Wood properties determined are moisture content, specific gravity, tracheid length, percent compression wood, percent extractives, chemical heartwood and cellulose content (plot average); separate determination, all properties, for corewood and outerwood.

ASSIGNMENT: D. E. Cole, Research Forester.

4—3. WOOD PROPERTIES OF OPEN-POLLINATED PROGENIES OF SLASH AND LOBLOLLY SELECT TREES. 111.0, 111.1, 111.3, 112.02, 141, 151.32. *Pinus elliottii, P. taeda.*

OBJECT: (1) To establish the correlation between the wood properties of various slash and loblolly select trees and their open-pollinated progenies; (2) to get an estimate of the heritability of these properties; (3) to see if any effect of geographic origin is detectable on wood properties; and (4) to establish a base for correlation between juvenile and mature characteristics of wood.

METHODS: Bark-to-bark 10mm. cores were pulled from 6-year-old trees in open-pollinated slash and loblolly progeny tests; 10 trees per plot, 4 replications; 13 slash clones, 3 loblolly clones, and about 12 check lots. Living parent trees will be resampled for wood properties and regraded for bole and crown characteristics. Progenies will be evaluated for bole and crown characteristics. Wood properties to be determined are moisture content, specific gravity, extractive content, tracheid length, summerwood cell wall thickness, percent compression wood, and cellulose content.

COOPERATOR: University of Florida

ASSIGNMENT: D. E. Cole, Research Forester

4—4. A COMPARISON OF THE WOOD PROPERTIES OF SLASH, LOBLOLLY, AND LONGLEAF PINE IN A MIXED NATURAL STAND. 111.0, 151.32. *Pinus elliottii, P. taeda,* and *P. palustris.*

OBJECT: (1) To compare the wood properties of these species where age, site, and spacing are uniform; (2) to determine which species produces the most wood under these conditions; and (3) to see if there is any correlation between species, wood properties, and bole and crown characteristics.

METHODS: Fifty sample trees, dominant or codominant, were selected for each species in a 15-acre old field stand, Bulloch County, Georgia. Bark-to-bark 10mm. cores were pulled at b.h. from each tree; height, diameter, and bole and crown were measured. Wood properties determined were moisture content, specific gravity, percent extractives, percent compression wood, percent corewood, tracheid length, and cellulose content; separate determinations, all properties, for corewood and outerwood. Then 5 trees with high specific gravity and 5 trees with low specific gravity were selected for each species; these trees were felled, weighed bolt by bolt and each bolt sampled with 10mm. cores and wedges. Finally, pulp and paper tests were run on one high and one low specific gravity tree of each species.

COOPERATOR: North Carolina State University.

ASSIGNMENT: D. E. Cole, Research Forester

4—5. LOCAL SEED SOURCE TESTS OF LOBLOLLY AND SLASH PINE FOR THE SAVANNAH, AUGUSTA, HODGE, LOUISIANA, AND HOPEWELL, VIRGINIA, WOODLANDS DISTRICTS. 111.1 *Pinus taeda, P. elliottii, P. virginiana, P. palustris.*

OBJECT: (1) To establish test plantings of slash and loblolly pine in the various major areas where the company collects seed, so as to compare the performance of seedlings from these areas in the areas where they originate and in other areas where that species might be planted; (2) to get a comparison of the performance of slash and loblolly by including one plot of loblolly in each of the slash blocks and vice versa; and (3) to design the plantings so that valid comparisons can be made with later plantings representing our various seed production areas and seed orchards.

METHODS: The design is as follows: Plots of 49 seedlings, spacing 7 x 9 feet; eight seed sources are represented in both the slash and loblolly blocks; each block is replicated four times. There are slash plantings at five locations; loblolly plantings are duplicated at four of these locations and there are loblolly plantings at three other locations. Slash plantings are located in Jasper County, South Carolina; Appling County, Georgia; Long County, Georgia; Baker County, Florida; and Bulloch County, Georgia. Loblolly plantings are duplicated in each of the first four slash plantings and also in Bleckley County, Georgia; Hancock County, Georgia; and Saluda County, South Carolina. Most of the slash plantings are on flatwoods or upper coastal plain soils; the loblolly plantings range from the flatwoods to the Piedmont.

This study, established in 1958-59, has been expanded to cover the Hodge, Louisiana, and Hopewell, Virginia, Districts.

The plantings in the Hodge District include six Louisiana, Arkansas, and East Texas loblolly seed sources, slash from Southeast Louisiana, the loblolly testers from the Hopewell and Savannah District tests, and the slash tester from the Savannah District test. There will be plantings at five different locations on company lands.

The plantings in the Hopewell District include six Virginia and North Carolina loblolly pine seed sources, one Virginia source of Virginia pine, the loblolly pine testers from the Hodge and Savannah Districts, and the slash pine tester from the Savannah District.

There will be plantings at six locations in Maryland, North Carolina, and Virginia.

A series of supplemental plantings are being established in the Savannah and Augusta Districts. This will include two Georgia sources of longleaf pine, slash pine from southeast Louisiana and Georgetown, South Carolina, a Georgia coastal plain loblolly pine seed source, the loblolly pine testers from the Hodge and Hopewell Districts, and the slash and loblolly pine testers from the Savannah and Augusta Districts.

Twenty-five tree plots and four replications are to be used in the Hodge and Hopewell Districts. Forty-nine tree plots are being used for the supplemental plantings in the Savannah and Augusta Districts but only the 25 trees in the middle of the plots will be measured. Spacing is 9 x 9 in all cases; planting sites have been chosen to sample a range of soil types. These plantings were established in winter of 1962-63.

ASSIGNMENT: D. E. Cole, Research Forester.

4—6. TESTING VARIATION AMONG INDIVIDUALS. 111.3. *Pinus elliottii, P. taeda.*

OBJECT: To locate individual trees with a high degree of resistance to *Cronartium fusiforme* for use in a program to develop strains resistant to *Cronartium fusiforme.*

METHOD: Open-pollinated progenies from trees being used in our slash and loblolly seed orchards and from sample trees on seed production areas are grown in plots and force-inoculated with *Cronartium fusiforme.* The following winter the infection rate is checked. Any which show appreciable resistance will be control-pollinated to determine if they pass on to their progeny any of their apparent resistance. Results to date are negative.

ASSIGNMENT: D. E. Cole, Research Forester

4—7. TESTING VARIATION AMONG INDIVIDUALS. 111.3. *Pinus taeda, P. elliottii.*

OBJECT: To establish open-pollinated progeny tests of various trees represented in slash and loblolly seed orchards which have been established in cooperation with the University of Florida and North Carolina State College.

METHOD: Test design and production of progeny test material will be done according to plans developed by cooperative forest tree improvement projects.

COOPERATORS: University of Florida; North Carolina State University.

ASSIGNMENT: D. E. Cole, Research Forester.

4—8. CROSSES OF NATURAL SLASH-LOBLOLLY HYBRID AND INDIVIDUAL SLASH AND LOBLOLLY SELECT TREES. 111.3, 112.02. *Pinus* spp.

OBJECT: To assay the genetic makeup of an apparent slash-loblolly hybrid by using pollen from it on both slash and loblolly select trees.

METHOD: This hybrid is represented in the open-pollinated progeny test of slash select trees referred to in project 3; its seedlings appear to be significantly higher than the average at the end of the first year in the field. First pollinations using pollen from this tree were made in the spring of 1962.

ASSIGNMENT: D. E. Cole, Research Forester.

4—9. ESTABLISHMENT OF CERTIFIED SEED PRODUCTION AREAS. 122.0, 122.2. *Pinus taeda, P. elliottii.*

OBJECT: To develop sources of seed of the best possible quality until our seed orchards come into quantity production.

METHODS: Establish slash and loblolly seed production areas according to the standards of the Georgia Crop Improvement Association. To date we have two certified loblolly production areas, one in Jeff Davis County, Georgia, and one in Hancock County, Georgia, with a total of 17 acres. We also have three certified slash seed production areas which total 42 acres; one in Long County, and two in Emanuel County, Georgia.

These areas are being fertilized and observations will be made on the effect of fertilization of seed production. Progeny tests will be established as seed becomes available. The first harvest on the oldest certified areas was in the fall of 1960.

Progeny tests were established during the 1962-63 winter in Bryan County, Georgia; Emanuel County, Georgia; Twiggs County, Georgia; Nassau County, Florida; and Jasper County, South Carolina, with 25 tree plots and 6 replications. Seed lots include slash and loblolly certified seed production area seed, slash and loblolly uncertified seed production area seed, seed collected from the isolation zone of certified seed production areas and from the adjacent unrogued stand, and the tester seed lots from our local seed source test.

In addition, seed production areas have been established on Company lands in Virginia and Louisiana using the Georgia Crop Improvement Association Standards (these areas are not certified, however).

Harvests were made in all Districts in 1961 and in the Hodge and Savannah-Augusta Districts in 1962.

A new certified area has been established in Effingham County, Georgia; the one in Long County, Georgia, has been increased in size.

ASSIGNMENT: D. E. Cole, Research Forester.

4—10. A COMPARISON OF THE WOOD PROPERTIES OF SWEETGUM, SYCAMORE, AND WHITE ASH IN A MIXED NATURAL STAND. 211.0, 211.3, 212.02, 251.32. *Liquidambar styraciflua, Platanus occidentalis, Fraxinus americana.*

OBJECT: (1) To compare the wood properties of these species under conditions where age, site, and spacing are uniform; (2) to determine relationship between wood properties and bole form, crown characteristics, growth rate, etc.; (3) to establish relationship between the wood properties of selected sample trees, ramets established vegetatively from them, and their open-pollinated progenies; and (4) to establish the relationship between wood properties, bole and crown characteristics, and the properties of pulp and paper.

METHODS: Twenty-five dominant or codominant sample trees were selected for each species in an even-aged natural stand, Hancock County, Georgia. Bark-to-bark 10mm. cores were taken at b.h. from each tree and they were measured for bole, crown, and growth characteristics. Seed and cuttings have been taken from the sycamore sample trees; an attempt will be made to collect seed from the ash and sweetgum next fall (1965). The sycamore cuttings are in the greenhouse and part of the seed will be sowed this spring. Wood properties to be determined are moisture content, specific gravity, fiber length, percent vessels by volume, cellulose content, percent corewood volume. Separate determinations will be made for all properties in the corewood and outerwood.

COOPERATOR: North Carolina State University.

ASSIGNMENT: D. E. Cole, Research Forester.

5. FLORIDA FOREST SERVICE
Tallahassee, Florida

5—1. SLASH PINE SEED PRODUCTION AREAS. 122.0. *Pinus elliottii.*

OBJECT: To collect as much seed as possible from phenotypically selected stands for the production of better seedlings in the State nurseries.

METHODS: A total of 600 acres of slash pine stands have been rogued of the poorer phenotypes and thinned to permit fuller crown development. One seed production area of 225 acres is located in the rolling uplands of west Florida on the Blackwater River State Forest. A second area containing 375 acres of former plantations on a flatwoods site is located in Camp Blanding Military Reservation near Starke, Florida.

ASSIGNMENT: R. A. Jordan, Reforestation Supervisor.

5—2. SEED ORCHARDS FOR PINE SEED PRODUCTION. 122.1. *Pinus elliottii, P. elliottii* var. *densa, P. palustris,* and *P. clausa.*

OBJECT: To improve the genetic quality of seedlings produced in State nurseries by collecting seed from selected clones of slash pine.

METHODS: Work on this project was begun in 1958 with the initial selection of over 400 phenotypically superior trees. These selections will be screened more closely and the final selections propagated by grafting. The ultimate goal is a total of 900 acres of seed orchards. Individual orchards will be located on the Blackwater River State Forest and the Withlachoochee State Forest.

Of this acreage approximately 37 acres will be *Pinus palustris,* approximately 50 acres will be *Pinus clausa,* 50 acres high gum yield *Pinus elliottii,* and approximately 15 acres of *Pinus elliottii* var. *densa.*

COOPERATORS: University of Florida.

ASSIGNMENT: R. A. Jordan, Reforestation Supervisor; H. R. Kok, Tree Improvement Supervisor; M. H. Zoerb, Jr., Tree Improvement Forester.

5—3. TROPICAL INTRODUCTION RESEARCH. 111.0, 211.0. Softwoods, hardwoods.

OBJECT: To introduce various tropical forest species that will grow and produce forest products in south Florida.

METHODS: Seeds of exotic tropicals are planted in our nursery located near Punta Gorda, Florida, and seedlings produced therefrom are planted on various sites in south Florida to test their performance on these sites and weather conditions. As species prove themselves worthy, they are placed on the market to the public for forest planting.

ASSIGNMENT: E. A. Schory, Tropical Research Forester.

6. FLORIDA FORESTS FOUNDATION

Fort Myers, Florida

6—1. SITE-PHOSPHATE STUDY. 211.0, 251.09. *Eucalyptus camaldulensis* (two seed sources), *E. grandis, E. grandis* × *camaldulensis, E. robusta, E. rudis.*

OBJECT: (1) To define the adaptability of promising eucalypts to representative southwest Florida land types, and (2) to determine if application of ground rock phosphate alters species adaptability patterns.

METHODS: The following land types are represented by single sites: acid flatwoods, sweet flatwoods, wet prairie, palmetto prairie, and dry ridge. Each site is an independent experiment with species planted with 0 and 1,250 pounds per acre of ground rock phosphate. The design is a four-replicated, randomized block with 25-tree square plots. Planted 1963.

COOPERATORS: American Agricultural Chemical Company; Babcock Florida Company; Lykes Bros. Inc.; Florida Forest Service.

ASSIGNMENT: George F. Meskimen, Research Forester.

6—2. SPECIES AND SEED SOURCE COMPARISON. 211.0, 211.1. *Eucalyptus botryoides, E. camaldulensis, E. grandis, E. robusta, E. rudis, E. saligna, E. tereticornis, Casuarina equisetifolia, C. glauca, Grevillea robusta.*

OBJECT: To compare the southwest Florida performance of rapidly growing exotic hardwood species; and to indicate the importance of seed source in species introduction.

METHODS: A 25-acre acid flatwoods site was disced, bedded, and planted in 1961. Design is randomized block with four replications and 64-tree square plots. Individual species represented by 2 to 12 seed sources; a total of 50 seed sources in the project.

COOPERATOR: The Collier Company.

ASSIGNMENT: George F. Meskimen, Research Forester.

6—3. OPEN-POLLINATED PROGENY TEST. 211.1, 211.3. *Eucalyptus grandis.*

OBJECT: (1) To compare performance of progenies from Florida-selected, plus phenotypes; (2) to compare progeny performance against the Australian seed sources from which the mother trees were selected; and (3) to compare several Australian seed sources.

METHODS: Open-pollinated seed was collected from eight 2-year-old trees selected for form and vigor under local conditions. Progeny were outplanted with seedlings from the original Australian seed sources and other recently introduced sources of *E. grandis.* Design is completely randomized with single-tree plots. Each progeny or source is represented by 48 to 100 trees. Planted 1964.

COOPERATORS: Lykes Bros. Inc.; Florida Forest Service.

ASSIGNMENT: George F. Meskimen, Research Forester.

7. IDA CASON CALLAWAY FOUNDATION

Pine Mountain, Georgia

7—1. PINE TREE BREEDING PROJECT. 112.01, 112.02. *Pinus palustris, P. taeda, P. echinata, P. elliottii.*

OBJECT: To develop improved strains of the four major species of southern pine for planting in west central Georgia (see project

8, SEFES, Macon, Georgia).

METHOD: Selections were made of slash, loblolly, shortleaf, and longleaf pines, and open-pollinated progeny tests established. Subsequently, controlled intra- and inter-specific crosses were made and planted in progeny tests. Emphasis is on growth, form, and disease resistance.

COOPERATOR: U. S. Forest Service, Southeastern Forest Experiment Station.

ASSIGNMENT: Eitel Bauer, Forester.

7—2. DEVELOPMENT OF COMMERCIAL SEED ORCHARDS OF SLASH AND LOBLOLLY PINE. 122.1. *Pinus taeda, P. elliottii.*

OBJECT: To establish sources of improved tree seeds for commercial use.

METHOD: Parental selections were made based on progeny tests in project 1 above. Orchards of open-pollinated seedlings from selected parents were established beginning in 1954. Acreages established are 2 loblolly and 49 slash pine. A study is being conducted on methods of grading individual trees and roguing the areas to insure seed of improved genetic constitution.

COOPERATOR: U. S. Forest Service, Southeastern Forest Experiment Station.

ASSIGNMENT: Eitel Bauer, Forester.

8. INTERNATIONAL PAPER CO., SOUTHLANDS EXPERIMENT FOREST

Bainbridge, Georgia

8—1. RACIAL STUDIES IN SLASH PINE. 111.1. *Pinus elliottii.*

OBJECT: (1) To test the possibility of ecotypic differentiation within slash pine and (2) to test the superiority of certain slash pine seed sources on wet and dry sites.

METHODS: Replicated tests of slash pine seed sources have been established in three locations; one in Decatur County, Georgia, one in Calhoun County, Florida, and the other in Mobile County, Alabama.

ASSIGNMENT: Roy W. Stonecypher, Silviculturist; Coleman Carr; Claude O'Gwynn.

8—2. TESTS OF COMPANY SEED PRODUCTION AREAS. 122.0. *Pinus.*

OBJECT: To test the gains obtained by use of planting stock derived from Company seed production areas.

METHODS: Replicated tests comparing nursery run to seed production area seedlings have been established in Florida and Alabama. Similar tests of all Company seed production areas are planned.

ASSIGNMENT: Roy W. Stonecypher, Silviculturist.

8—3. TESTS OF COMPANY SEED ORCHARDS. 122.1. *Pinus.*

OBJECT: To progeny test all Company seed orchard selection.

METHODS: Replicated progeny tests of each seed orchard or section are being established in at least two locations in each Company region.

ASSIGNMENT: Roy W. Stonecypher, Silviculturist.

8—4. USE OF ELECTRONIC COMPUTER IN ANALYZING FOREST GENETICS RESEARCH. 153. *Pinus.*

OBJECT: To develop computer programs to efficiently manipulate and analyze data obtained from basic quantitative genetics studies and progeny tests.

METHODS: Computer programs are being written for use on the Company's IBM 1620 computer.

ASSIGNMENT: Roy W. Stonecypher, Silviculturist.

9. LOUISIANA STATE UNIVERSITY, SCHOOL OF FORESTRY AND WILDLIFE MANAGEMENT

Baton Rouge, Louisiana

9—1. EFFECTS OF GEOGRAPHIC SOURCE OF SEED ON PLANTED LOBLOLLY PINE. 111.1. *Pinus taeda.*

OBJECT: To discover if there are any important differences among sources of loblolly pine which would warrant delineating seed collection zones within the state.

METHODS: (1) Exploratory plantation established in coastal plain soil in Washington Parish, La., in winter of 1954. There were four seed sources. A randomized block design was used, with four replications of each seed source. Seedlings were planted at 6 x 6 spacing in a square of 11 rows of 11 trees each, the two outermost rows serving as border strips. (2) January 1958 plantations: five sources, three locations—Washington, East Feliciana, and Vernon Parishes. (3) January 1959 plantations: 12 sources, Claiborne Parish; 10 sources, East Feliciana Parish. Statistical design of 1958 and 1959 plantations: See "Standardized Working Plan for Local Tests of Seed Source," prepared by the Committee on Southern Forest Tree Improvement, Subcommittee on Geographic Source of Seed, dated October 25, 1951. The study is part of the S-23 project.

ASSIGNMENT: A. B. Crow, Professor.

9—2. Natural variation in American sycamore. 211.3. *Platanus occidentalis* L.

OBJECT: To assess the natural variation in botanical features and certain wood characteristics of American sycamore; and to assess the relationship of such variation to the existence of geographic races, clines, or to environmental influences.

METHODS: (1) Variation will be determined in fiber length, growth rate, specific gravity, and ash content of increment-core samples, and in leaf, fruit, and twig characteristics collected from within the natural range of sycamore and will be correlated with geographic, climate, or site characteristics. (2) Outplanting will be made of trees grown from seed from geographic locations throughout the natural range. The study is part of the S-23 project.

ASSIGNMENT: P. J. Fogg, Instructor.

10. NORTH CAROLINA STATE UNIVERSITY, SCHOOL OF FORESTRY
Raleigh, North Carolina

10—1. Collection and study of Mexican pines. 11. *Pinus.*

OBJECT: To collect seed, foliage, and wood specimens of various Mexican pines. To test these seed in a number of plantings throughout the Southeastern United States, Brazil, and Hawaii.

METHOD: Collections were made from a total of 110 trees representing 15 species by a 6-man team in 1952, sponsored by six industries and North Carolina State. Pilot-plant studies are underway throughout the southeast.

COOPERATORS: Hiwassee Land Company (Bowaters); Continental Can Company; Kimberly-Clark Corporation; Champion Papers Inc.; West Virginia Pulp and Paper Company; Union Bag-Camp Paper Corporation.

ASSIGNMENT: L. C. Saylor, Assistant Professor; R. L. McElwee, Geneticist; B. J. Zobel, Professor; R. C. Kellison, Liaison Geneticist; Foresters from cooperating agencies.

10—2. Variation and inheritance of wood properties. 111, 141, 151.32, 211, 241, 251.32. *Pinus taeda, P. elliottii, P. serotina, P. strobus, P. virginiana, Liriodendron tulipifera, Liquidambar styraciflua.*

OBJECT: (1) To determine variation within trees, among trees, and among stands in wood quality factors; (2) to isolate wood quality factors important in final products; and (3) to determine inheritance patterns of the factors.

METHODS: Variation in wood properties among trees in different geographic races is determined. Wood variation with a tree; the basic inheritance patterns of wood specific gravity; and the inter-relations of wood characteristics are determined as well as gross heritabilities and parent-offspring relationships. The occurrence and importance of compression wood has been evaluated; the effect of certain wood and fiber qualities on final product will be worked out to aid selective breeding programs. The studies are part of the S-23 project.

COOPERATORS: Members of cooperators in Tree Improvement Program, especially International Paper Company, Union Bag-Camp Paper Corporation, Weyerhaeuser Timber Company, Continental Can Company (See Project No. 6), State and Federal Research Organizations, Staffs of cooperating companies.

ASSIGNMENT: B. J. Zobel, Professor; R. C. Kellison, Liaison Geneticist; J. W. Duffield, Professor; C. Browne, Laboratory Technician; M. Mathias and C. Kennedy, Research Assistants; Graduate students: F. Taylor (yellow-poplar); K. A. Taft (yellow-poplar); M. A. Taras (loblolly pine); C. Posey (loblolly pine); R. W. Stonecypher (loblolly pine); J. E. Kundt (Virginia pine); K. W. Kang (pond pine and pond × loblolly hybrid); T. Shelbourne (loblolly and slash pine); D. G. Nikles (Caribbean slash pine).

10—3. HYBRIDIZATION, INTROGRESSION, AND CYTOGENETICS. 111, 112.01, 141, 151.1, 211, 241, 251.1. *Pinus, Liriodendron tulipifera, Liquidambar styraciflua.*

OBJECT: (1) To determine chromosome morphology in the genus *Pinus;* (2) determine the chromosome pairing patterns among pines; (3) conduct a "directed breeding" hybridization program; and (4) investigate variation, inheritance, and breeding characteristics of yellow-poplar and sweetgum.

METHODS: The chromosome morphology of over 70 species of pines from seed collected in Mexico and other areas are being studied and test plantings of trees are being made. The chromosome pairing patterns among wide crosses in pines produced at the Institute of Forest Genetics at Placerville, Institute of Forest Genetics at Gulfport, and Texas Forest Service, are being worked out. Hybridization to produce a tree suitable to grow on certain problem sites is being conducted for industrial use (Union Bag-Camp and West Virginia Pulp and Paper Companies). A study of introgression is being made based on the natural hybrid between loblolly and longleaf pine, loblolly and pond pine, and of the slash pine complex in the Caribbean. Morphological and growth characteristics of native sweetgum are being studied to work out individual, clinal, and ecotypic variation patterns. The degree of compatibility for yellow-poplar and sweetgum is being determined through use of recently developed techniques for controlling pollination in these two species.

COOPERATORS: B. Smith, N. C. State; W. Critchfield, Institute of Forest Genetics at Placerville; E. B. Snyder, Institute of Forest Genetics at Gulfport; Union Bag-Camp Paper Corporation; West Virginia Pulp and Paper Company; Halifax Company; numerous company foresters.

ASSIGNMENT: L. C. Saylor, Assistant Professor; B. J. Zobel, Professor; J. W. Duffield, Professor; G. Namkoong, Research Forester; Institute of Forest Genetics at Gulfport (U. S. Forest Service); K. W. Kang, Graduate Assistant (South Korea); D. G. Nikles, Graduate Student (Australia); J. H. Roberds, Graduate Assistant; R. C. Kellison, Liaison Geneticist; J. Hofmann, Albemarle.

10—4. INHERITANCE OF PHYSIOLOGICAL AND CLOSELY RELATED CHARACTERISTICS. 111, 141, 211, 241. *Pinus taeda.* Hardwoods.

OBJECT: To determine variation and inheritance of physiological and closely related characteristics in some forest trees.

METHOD: Studies are underway on photosynthetic efficiency, differential photoperiodic reaction, nutrient content of needles, dry matter content of needles, salt-tolerant races of loblolly pine, drought-tolerant races of loblolly pine, and bark thickness in young loblolly pine.

COOPERATORS: Members of North Carolina State-Industry Cooperative Program.

ASSIGNMENT: T. O. Perry, Associate Professor; B. J. Zobel, Professor; J. W. Duffield, Professor; T. E. Maki, Head, Department of Forest Management; F. Ledig, Graduate Assistant; W. Beineke, Graduate Assistant; C. Franklin, Graduate Assistant; S. Land, Graduate Assistant; T. Shelbourne, Graduate Assistant.

10—5. PROVENANCE STUDIES. 111.1, 211.1. *Pinus, Liquidambar styraciflua, Liriodendron tulipifera.*

OBJECT: To determine the existence of geographic races in certain forest tree species.

METHODS: A study of racial variation in loblolly, established in 1958, consists of 20 acres of outplantings in the coastal plain replicated eight times in the design. A study of sweetgum was installed in 1959 with plantings of trees from various locations in North Carolina, and planting of seed from areas throughout the species range is completed. A study with yellow-poplar has been started, comprising investigation of wild stands in North Carolina from the seacoast to the mountains, and the growing of seedlings from different stands for planting in areas on the coastal plain and Piedmont. In addition, studies are in progress for several other species of pines, including *P. virginiana.* A region-wide provenance study involving 140 individual tree seed lots (open-pollinated) from 28 locations is being established throughout the range of sweetgum in the South with seed from the 1964 and 1965 seed crops. All cooperators in the Hardwood Research Program are taking active parts in this study.

COOPERATORS: Members of North Carolina State-Industry Cooperative Program.

ASSIGNMENT: B. J. Zobel, Professor; R. C. Kellison, Liaison Geneticist; R. L. McElwee, Geneticist.

10—6. DEVELOPMENT AND TESTING OF PINE SEED ORCHARDS FOR COMMERCIAL USE. 111.3, 122. *Pinus.*

OBJECT: (1) To develop and apply selective breeding methods for mass production of improved seed with maximum genetic gain in the shortest time, and (2) to develop a tree bank with a broad genetic base from which to draw for improved, future seed orchards.

METHODS: (1) Trees used in the establishment of seed orchards by forest industries are selected, graded, and progeny tested. Progeny testing is by open- and control-pollinated seed, using a 4-tester system for the latter. Data from progeny tests will be used to develop improved selection indices. Seed production areas are developed for use until seed orchards begin production. Seed orchard management procedures, particularly fertilizer and irrigation schedules, will be worked out. (2) Inasmuch as future seed orchards may need genetic types much different from those we have today, it is prudent to develop a "gene pool" by preserving different genotypes in a tree bank. Trees that are well-formed and fast-growing and which also react well to fertilizer, intensive management, or cultivation are examples. Several hundred clones have been established to date; wide crosses within species and inter-specific crosses are made to insure a wide variety of different and new genotypes.

COOPERATORS: Cooperating agencies in the North Carolina State-Industry Tree Improvement Program. Organizations included are: Albemarle Paper Manufacturing Company, Catawba Timber Company (Bowaters), Champion Papers Incorporated, Chesapeake Corporation of Virginia, Continental Can Company, Georgia Kraft Company, Hiwassee Land Company (Bowaters), International Paper Company, Kimberly-Clark Corporation, American Can Company, North Carolina Forest Service, Riegel Paper Corporation, South Carolina Forestry Commission, Tennessee River Pulp and Paper Company, Union Bag-Camp Paper Corporation, West Virginia Pulp and Paper Company, Weyerhaeuser Paper Company.

ASSIGNMENT: B. J. Zobel, Professor; R. C. Kellison, Liaison Geneticist; L. C. Saylor, Assistant Professor; T. E. Maki, Professor; T. O. Perry, Associate Professor; J. W. Duffield, Professor; Personnel from each cooperating organization; 15 graduate students.

10—7. STATISTICAL METHODS IN FOREST GENETICS. 141, 153, 253. Softwoods, hardwoods.

OBJECT: (1) To develop statistical methods applicable to quantitative genetics and to progeny testing forest trees, and (2) determine the role of inbreeding and selfing in pine.

METHOD: Assessment is under way to determine design efficiency and analyses that are characteristic of studies in quantitative genetics. Studies of the importance of plot size have been included, as well as comparative efficiencies between open- and control-pollinated progenies from the same trees. Extent and importance of inbreeding will be studied.

COOPERATORS: International Paper Company (Southlands Experiment Forest); National Science Foundation; National Institute of Health; Genetics Department, North Carolina State University.

ASSIGNMENT: R. W. Stonecypher, International Paper Company; G. Namkoong, Research Forester, Institute of Forest Genetics at Gulfport (U. S. Forest Service); J. H. Roberds, Graduate Assistant; H. F. Robinson, Head, Institute of Biology, N. C. State University; C. Cockerham, Institute of Statistics, N. C. State University.

10—8. INHERITANCE PATTERNS, VARIANCE COMPONENTS, AND BREEDING PROCEDURES. 141, 241. *Pinus,* hardwoods.

OBJECT: To determine inheritance patterns, variance components, and best breeding procedures for several species of pine and hardwoods.

METHODS: Inheritance patterns and variance components are being obtained from a large cooperative study located largely on the Southlands Experiment Forest of the International Paper Company. Characteristics such as needle anatomy, growth habit, wood properties, physiological reactions, disease resistance, and many others are being studied. Plantings have been made in the greenhouse and on Piedmont and coastal plain soils. Both open-pollinated and control-pollinated seed are used; the latter is a modification of N. C. State Design I, (male group method). Clonal material from the same parents used for open- and control-pollination will be established. Selected parent trees and some of their progeny will be cut and pulped to determine inheritance of certain wood characteristics. Also, seed orchard crosses from progeny tests will be used in studies of variance components. Juvenile-mature correlations will be computed. Variance components of yellow-poplar and Virginia pine will be determined by means of diallel crosses. Inheritance patterns in sweetgum and yellow-poplar will be determined from a series of open-pollinated progeny tests.

COOPERATORS: International Paper Company; Wood Products Department, N. C. State University; Members of cooperative Tree Improvement Program; Genetics Department, N. C. State; National Science Foundation; National Institute of Health.

ASSIGNMENT: B. J. Zobel, Professor; R. C. Kellison, Liaison Geneticist; R. W. Stonecypher, Silviculturist, International Paper Company; H. F. Robinson, Head, Institute of Biology, N. C. State; J. H. Roberds, Graduate Assistant; C. Franklin, Graduate Assistant; K. A. Taft, Graduate Assistant; B. B. Kinloch, Jr., Graduate Assistant; G. Namkoong, Research Forester, Institute of Forest Genetics at Gulfport, U. S. Forest Service.

10—9. POLLEN FLIGHT CHARACTERISTICS. 154.5. *Pinus*.

OBJECT: To determine the horizontal and vertical aspects of pollen flight in addition to the viability pattern of long-flight pollen, and to determine the value of radio-active materials to solution of pollen problems.

METHODS: Studies of pollination are essential to understanding the pattern among trees and the evolutionary significance of pollen spread. Future work will involve the use of radio-active materials to add to the information now available on pollen problems. Of immediate, practical importance is information obtained on requirements for isolation of seed orchards and seed production areas and on degree of contamination to be expected in seed orchards. Differential pollination by individual trees will be studied.

COOPERATORS: Savannah River Project, Atomic Energy Commission.

ASSIGNMENT: R. L. McElwee, Geneticist; B. J. Zobel, Professor; J. B. Hatcher, Forester, U. S. Forest Service.

10—10. VARIATION AND INHERITANCE OF WOOD PROPERTIES. 211, 241, 251.32. *Quercus phellos, Quercus nigra, Nyssa sylvatica* var. *biflora, N. aquatica*.

OBJECT: (1) To determine variation within tree, among trees, and among stands in wood quality factors; (2) to isolate good quality factors important in final products; and (3) to determine inheritance patterns of the factors.

METHODS: Variation in wood properties within trees, among trees, and geographic areas is determined. The basic inheritance patterns of wood specific gravity, and the inter-relations of wood characteristics are determined. The effect of certain wood and fiber qualities on final product will be worked out.

COOPERATORS: Members of the Cooperative Hardwood Research Program; State and Federal research organizations, staffs of cooperating agencies; Albemarle Paper Manufacturing Co.; Champion Papers; Continental Can Co., Inc.; Georgia Pacific Corp.; International Paper Co.; Kimberly-Clark Corp.; Riegel Paper Corp.; Riverside Manufacturing Co.; Union Bag-Camp Paper Corp.; Weyerhaeuser Co.; and Williams Furniture Co.

ASSIGNMENT: R. L. McElwee, Geneticist; J. W. Duffield, Professor; J. B. Faircloth, Laboratory Technician; R. A. Usanis, Graduate Student.

10—11. VEGETATIVE PROPAGATION OF FOREST TREES. 251.02. *Liquidambar styraciflua, Liriodendron tulipifera, Platanus occidentalis, Fraxinus americana.*

OBJECT: To develop methods of vegetative propagation for sweetgum, yellow-poplar, sycamore, white ash.

METHODS: Methods of grafting in the greenhouse and field are under way for all species.

COOPERATORS: Several cooperating industries.

ASSIGNMENT: R. L. McElwee, Geneticist; B. J. Zobel, Professor; T. Shelbourne, Graduate Assistant.

11. TENNESSEE VALLEY AUTHORITY, DIVISION OF FORESTRY DEVELOPMENT

Norris, Tennessee

11—1. SELECTION AND TESTING OF IMPROVED FOREST TREES. 111.0, 111.3, 211.0, 211.3. *Pinus taeda, P. echinata, P. strobus, P. virginiana, Castanea dentata, Populus* spp., *Juniperus virginiana, Juglans nigra, Prunus serotina, Quercus* spp., *Acer rubrum, Betula verrucosa, Liriodendron tulipifera.*

OBJECT: To select and develop trees of most rapid growth, highest quality, and greatest economic usefulness for growing in the Tennessee Valley.

METHODS: An active search is being conducted for superior pine and hardwood trees—to date 136 superior selections of loblolly, shortleaf, Virginia, and white pine, 117 selections of black cherry, black walnut, yellow-poplar, and northern red, chestnut, and white oaks for pulpwood and timber production, and 8 selections of yellow-poplar, maple, and birch species with figured wood for veneer have been made. Twenty-seven selections of cottonwood are being compared for their form and growth qualities in four plantations in the Valley and response to nutrients. Four selections of American chestnut were propagated to test their blight resistance, and records are being kept on two timber-type Asiatic and hybrid chestnut plantings. A total of 2,400 pine super-seedlings at the Clinton Nursery have been selected and outplanted in order to determine whether nursery selection is a feasible method of discovering genetically superior strains of trees. Arboretums and other test plantings of forest species in the Norris, Tennessee, area total 21. A columnar redcedar progeny test has been established at three locations in the Valley and pine progeny tests at seven locations.

COOPERATORS: Hiwassee Land Company, Calhoun, Tennessee; Tennessee River Pulp and Paper Company, Counce, Tennessee; Tennessee Department of Conservation, Nashville, Tennessee; U. S. Forest Service, Southeastern Forest Experiment Station, Asheville, North Carolina, and Northeastern Forest Experiment Station, Laurel, Maryland; University of Tennessee Agricultural Experiment Station, Knoxville, Tennessee.

ASSIGNMENT: A. A. Foster, Supervisor, Forest Tree Improvement Section; T. G. Zarger, Staff Forester; K. A. Taft, Staff Forester; D. C. Forbes, Staff Forester.

11—2. SEED ORCHARDS AND SEED PRODUCING AREA TESTS. 122.0, 122.1. General.

OBJECT: To determine optimum practices for establishing and caring for seed orchards and seed production areas; to promote establishment of seed orchards and seed producing areas in the Tennessee Valley so that future reforestation programs can be carried out with trees of optimum growth and quality potential.

METHODS: Twelve pine seed orchards have been completed. Production of grafted planting stock is being continued to replace those which die. Experience in establishing and maintaining seed orchards is being noted to provide information on sound orchard management practices to assure an abundant, regular, and dependable seed supply.

COOPERATORS: Alabama Division of Forestry, Montgomery, Alabama; Carter Patten, Chattanooga, Tennessee; Georgia Forestry Commission, Macon, Georgia; Hassell and Hughes Lumber Company, Waynesboro, Tennessee; Hiwassee Land Company, Calhoun, Tennessee; Kentucky Division of Forestry, Frankfort, Kentucky; Tennessee River Pulp and Paper Company, Counce, Tennessee; Tom B. Swann, Dandridge, Tennessee.

ASSIGNMENT: A. A. Foster, Supervisor, Forest Tree Improvement Section; T. G. Zarger, Staff Forester.

11—3. PROPAGATION TESTS. 151.02, 251.02. General.

OBJECT: To develop and test vegetative and other methods of propagating and producing select plant material.

METHOD: Various vegetative propagation methods (grafting, budding, air layering, and rooting) have been adapted, developed and tested for the production of select hardwood and pine planting stock used in TVA's forest tree improvement, nut tree, and other tree crops research work.

COOPERATORS: University of Tennessee Agricultural Experiment Station, Knoxville, Tennessee.

ASSIGNMENT: A. A. Foster, Supervisor, Forest Tree Improvement Section; T. G. Zarger, Staff Forester; John F. Hatmaker, Propagator.

11—4. SEED SOURCE TESTS. 111.1, 211.1. *Pinus taeda, P. echinata, P. virginiana, P. strobus, Juniperus virginiana, Acer saccharum.*

OBJECT: To determine the geographic limits within which seed should be collected for production of forest planting stock used within the Tennessee Valley.

METHODS: A total of 25 loblolly, shortleaf, and Virginia pine, redcedar and sugar maple seed source tests have been established. Significant differences in survival and height growth have been observed among some of the sources but delineation of provenance limits for collecting seed that will be used within the Valley is as yet premature. Criteria used in determining optimum provenance boundaries include growth rate, resistance to forest pests, response to environmental factors, and other tree or wood characteristics.

COOPERATORS: One or more of the following: Committee on Southern Forest Tree Improvement; Kimberly-Clark Corporation, Coosa River Newsprint Division, Coosa Pines, Alabama; Tennessee Fish and Game Commission, Nashville, Tennessee; Tennessee River Pulp and Paper Company, Counce, Tennessee; Tennessee State Division of Forestry, Nashville, Tennessee; U. S. Forest Service, six research centers of Central, Southern, and Southeastern Forest Experiment Stations; University of Maryland, Natural Resources Institute, College Park, Maryland; University of Tennessee Agricultural Experiment Station, Knoxville, Tennessee; and University of the South, Sewanee, Tennessee.

ASSIGNMENT: A. A. Foster, Supervisor, Forest Tree Improvement Section; T. G. Zarger, Staff Forester.

12. TEXAS FOREST SERVICE

College Station, Texas

12—1. DEVELOPMENT OF DROUGHT-HARDY STRAINS OF LOBLOLLY PINE. 111.2, 151.07. *Pinus taeda.*

OBJECT: To develop a drought-hardy strain of loblolly pine for reforestation on severe sites.

METHODS: Five extremely severe sites and five or more individual trees on each site were selected along the westernmost fringe of the southern pine region. Progeny tests are made by individual mother trees from each site to determine (1) the most promising sites and (2) most drought-hardy selections on that site. Mother trees are tested by means of four pollen parents. Progeny are grown under uniform nursery conditions, then lifted as 1-0 stock, morphologically graded, root pruned, and subjected to imposed and controlled drought in the field as 1-1 stock. After progeny testing, crosses between the most desirable parents will be placed in seedling seed orchards for the future production of drought-hardy seed.

LOCATION: East Texas. Deep sandy soils.

ASSIGNMENT: J. P. van Buijtenen, Silviculturist.

12—2. SELECTION OF ONE-YEAR-OLD LOBLOLLY PINE NURSERY SEEDLINGS FOR OUTSTANDING GROWTH CHARACTERISTICS. 111.3. *Pinus taeda.*

OBJECT: To determine if outstanding 1-year-old loblolly pine seedlings continue to show height growth superiority following outplanting in the field.

METHODS: One-year-old loblolly pine seedlings possessing (1) superior height, (2) average height, and (3) inferior height were selected from standard nursery beds in the fall of 1953, 1954, and 1955. One hundred seedlings of each class were planted in rows at 6 x 8 spacing (25 plant rows, 4 replications) for 3 successive years. Observations on height growth are made yearly.

LOCATION: Cherokee County, Texas. Sandy soil.

ASSIGNMENT: J. P. van Buijtenen, Silviculturist.

12—3. ANATOMICAL FACTORS RESPONSIBLE FOR VARIATIONS IN WOOD SPECIFIC GRAVITY. 111.3, 151.32. *Pinus taeda, P. elliottii.*

OBJECT: (1) To determine the contributions of various anatomical factors to changes in wood specific gravity, and (2) to determine whether it is possible to breed selectively for those factors which increase wood specific gravity without adversely affecting pulp and papermaking properties.

METHODS: Wood samples from selections for high and low wood specific gravity will be analyzed for the factors contributing to wood specific gravity. The factors will be examined for their effect on pulp and papermaking properties and the possibility of using them as criteria for selection.

ASSIGNMENT: J. P. van Buijtenen, Silviculturist.

12—4. GENETIC CONTROL OF WOOD DENSITY. 112.02, 151.321. *Pinus taeda.*

OBJECT: To determine the heritability of wood specific gravity in loblolly pine.

METHODS: On the basis of several thousand wood specific gravity determinations, 30 loblolly pine trees have been selected from 15 sites in East Texas. Two trees were selected from each site, one possessing high wood density, the other low wood density. These selected phenotypes formed the basis for making specific crosses involving high x high, low x low, and high x low wood densities. Controlled pollinated seed were grown at 4 x 6 spacing in replicated blocks in uniform nursery beds. The bole wood of 100 2-0 and 1-0 seedlings from each cross is being analyzed for wood density. The mean wood density values of each progeny are compared with the specific gravity of the core wood of the respective parents. From these determinations it will be possible to estimate the rigidity of genetic control over this important wood property. The same progenies were field planted at 6- x 8-foot spacing for further analysis at a more mature age. The study is part of the S-23 project.

LOCATION: Cherokee County, Texas.

ASSIGNMENT: J. P. van Buijtenen, Silviculturist.

12—5. SEED ORCHARD ESTABLISHMENT AND OPERATION. 122.1. *Pinus taeda.*

OBJECT: To determine the best way to handle a seed orchard to produce an early, heavy, and sustained yield of seed.

METHODS: In 1955-1956 grafted scions of loblolly pine were planted in blocks at 30 x 30 and 20 x 20 spacing. The blocks contain 12 and 16 grafts respectively. Total of 18 blocks at 30 x 30 and 24 blocks at 20 x 20. One-half of the area is disc cultivated, the other half is mowed. The blocks form the basic unit for fertilization studies. Three levels of fertilization are used in factorial design, with at least three replications (blocks) per treatment in both cultivated and non-cultivated sections. The levels of fertilizer are: (a) high—600 lbs. N, 500 lbs. P and K/acre; (b) intermediate—200 lbs. N, P, and K/acre; and (c) controls—none. Fertilizer applications are made in early spring. Soil analyses are made each fall to determine nutrient-supplying capacity under each treatment.

LOCATION: Cherokee County, Texas. Light sandy soil.

ASSIGNMENT: J. P. van Buijtenen, Silviculturist.

12—6. QUANTITATIVE GENETICS STUDY IN LOBLOLLY PINE. 141. *Pinus taeda.*

OBJECT: (1) To determine the mode of inheritance of characters of commercial importance, and (2) to develop selection indices based on genetic information.

METHODS: Heritabilities and genetic correlations will be determined from existing plantations in the Texas Forest Service Cooperative Tree Improvement Program. These data will be used for the construction of selection indices and for the evaluation of various breeding systems.

LOCATION: Cherokee and Nacogdoches Counties, Texas.

ASSIGNMENT: J. P. van Buijtenen, Silviculturist.

12—7. HERITABILITY STUDY IN LOBLOLLY PINE. 141. *Pinus taeda.*

OBJECT: To determine the heritability of a number of anatomical, morphological, and physiological characteristics of loblolly pine.

METHODS: Two loblolly pine populations in Texas will be sampled as part of a cooperative study of the Southern Institute of Forest Genetics and the Texas Forest Service. The sample trees will be evaluated by an incomplete series of diallel crosses. The seedlings produced will be tested on a number of sites in Texas and Louisiana. The heritability estimates will be obtained from parent progeny correlations and from an analysis of variance of the progeny data.

COOPERATORS: Institute of Forest Genetics at Gulfport.

ASSIGNMENT: J. P. van Buijtenen, Silviculturist.

12—8. ATTEMPTS TO STIMULATE EARLY CONE PRODUCTION IN PLANTED LOBLOLLY PINE SEEDLINGS. 151.01, 151.03. *Pinus taeda.*

OBJECT: To determine the length of time required to bring loblolly pine trees into flowering and cone production through the application of different cultural treatments and techniques.

METHODS: Three replicated plots approximately 2 acres in size were planted to 1-year old seedlings in the fall of 1958 at 15 x 15 spacing. Each replication is divided into four blocks containing 90 seedlings each; these blocks constitute the basic amount for fertilization treamtents. Each block will receive different ratios of available nitrogen and phosphorus. Potassium will be maintained at a constant level. These levels in pounds per acre are:

Block	*Nitrogen*	*Phosphorus*	*Potassium*
I	600	0	200
II	0	600	200
III	600	600	200
IV	0	0	200

Soil analyses are made each fall following fertilizer application in spring.

LOCATION: Cherokee County, Texas.

ASSIGNMENT: J. P. van Buijtenen, Silviculturist.

12—9. STUDY OF CHEMICAL CHANGES ASSOCIATED WITH ROOTING IN PINES. 151.02. *Pinus taeda, P. elliottii.*

OBJECT: (1) To study the metabolic changes which are associated with the initiation and development of roots, and (2) to determine if growth regulators are present which specifically influence rooting.

METHODS: Cuttings will be propagated in the greenhouse under an intermittent mist system. At regular intervals cuttings will be removed from the rooting bed. The basal inch of these stems of the cuttings will be analyzed for free amino-acids, sugars, and protein amino acids. In a separate study samples will be taken at regular intervals for the determination of the content of growth regulators.

LOCATION: Brazos County, Texas.

ASSIGNMENT: J. P. van Buijtenen, Silviculturist.

12—10. THE INFLUENCE OF CROWN PRUNING ON PRODUCTION AND DISTRIBUTION OF CONES ON LOBLOLLY PINE. 154.3. *Pinus taeda.*

OBJECT: To determine best method for shaping trees in managed seed orchards.

METHODS: This study was established during the summer of 1958 in an area with deep sand soil. Pruning was done in 3- and

5-year-old planted stands and also in a natural old field stand about 25 years old which was already producing rather heavy cone crops. Treatments applied include severe (½ the total crown) and light (¼ of total crown) topping as well as trimming all lateral limbs on other individual trees. Retreatments will be applied over a period of several years to those trees that were lightly pruned and cone production of the treated versus the check trees will be recorded periodically. Two hundred and forty trees are involved in the study.

LOCATION: Cherokee County, Texas.

ASSIGNMENT: J. P. van Buijtenen, Silviculturist.

13. UNION BAG-CAMP PAPER CORPORATION
Savannah, Georgia

13—1. Slash pine seed producing area progeny test. 111.3, 122.0. *Pinus elliottii.*

OBJECT: To establish relative, and if possible, absolute degrees of genetic improvement in progenies of three different slash pine seed producing areas.

METHODS: Five seed sources are tested: (1) Control, woods-run seed; (2) Ogeechee Forest seed producing area; (3) Altamaha Forest seed producing area; (4) Oconee Forest seed producing area; and (5) control-pollinated progeny (miscellaneous mixture including some polymix progeny as well as specific crosses.) All five seed sources are outplanted on each of three forests where seed producing areas are located. Each outplanting uses a Latin square design with individual plots consisting of 121 trees. Of the total number of seedlings in each plot, 49 are sample trees, others serve as isolation. All plantings are on a 6 x 10 spacing. Outplantings are established on cutover woods sites with a double disking for site preparation. The study was established in January 1963.

ASSIGNMENT: Barry F. Malac, Director.

13—2. Progeny test of crosses for specific characteristics. 111.3, 153. *Pinus* spp.

OBJECT: To obtain early indications of heritability in clones available for testing, to aid in evaluating the phenotypic selection system, and to assess the value of row plot planting designs.

METHODS: A randomized block design was used with 10 blocks, each containing ten 10-tree row plots. Six specific crosses, one general seed orchard lot, and three lots of check material were used in the test. Outplantings were at 8- x 8-foot spacing with one row isolation strip between blocks.

ASSIGNMENT: Robert L. Koenig, Research Forester.

13—3. Hybridization for difficult sites. 112.01. *Pinus elliottii, P. clausa, P. palustris, P. serotina, P. glabra, P. virginiana,* and *P. rigida.*

OBJECT: To develop trees well adapted for outplanting on problem sites in coastal Georgia and South Carolina, and in eastern Virginia.

METHODS: Controlled pollinations are being made in various combinations using specific tree selections of the following pine species: slash, sand, longleaf, pond, spruce, Virginia, and pitch. Some crosses are first being made on a trial basis to determine the feasibility of continuing with them on a "pilot plant" approach.

COOPERATOR: North Carolina State University (Drs. L. C. Saylor and Bruce J. Zobel).

ASSIGNMENT: Robert L. Koenig, Research Forester.

13—4. Fertilization of slash pine seed orchards. 151.03. *Pinus elliottii.*

OBJECT: To test the effects of various levels of nitrogen (N) and potash (K_2O) on increment of grafted seed orchard trees.

METHODS: There are 6 different treatments imposed on 15 different clones. Treatments are as follows:

Elemental N	*Elemental K_2O*
– – – *(ounces per tree)* – – –	
0	0
36	0
72	0
0	21
36	21
72	21

COOPERATOR: University of Florida (Drs. W. L. Pritchett and R. E. Goddard).

ASSIGNMENT: Robert L. Koenig, Research Forester.

13—5. FERTILIZATION OF SLASH PINE SEED ORCHARDS FOR CONE PRODUCTION. 151.03. *Pinus elliottii.*

OBJECT: To determine the effects of various levels of nitrogen upon the flowering habits of young slash pine ramets.

METHODS: Four different treatments with four replications were applied to ten clones. Available nitrogen at rates of 9, 8, 16, and 32 ounces per tree was applied by surface application. All trees received base application of 6.8 lbs. of 0-14-14.

COOPERATOR: University of Florida (Drs. W. B. Pritchett and R. E. Goddard).

ASSIGNMENT: Robert L. Koenig, Research Forester.

13—6. FERTILIZATION OF SLASH PINE SEED ORCHARD FOR CONE PRODUCTION. 151.03. *Pinus elliottii.*

OBJECT: To stimulate flower production in slash pine orchards through application of large dosages of inorganic fertilizers.

METHODS: Treatments of 0, 16, and 24 lbs. of 10-10-10 granular fertilizer were applied with one application to five clones. Thirty healthy 5-year-old ramets, six each of five clones, were randomly assigned the three treatments. Fertilizer was applied on the surface, within the dripline of the tree crown. The study was established in 1961.

ASSIGNMENT: Robert L. Koenig, Research Forester.

13—7. FERTILIZING AND SPRAYING SEED-PRODUCING AREAS FOR BETTER CONE PRODUCTION. 151.03, 152.0. *Pinus* spp.

OBJECT: Determination of quantitative response in cone production to: (1) fertilizer application; (2) periodic spraying for cone insects; and (3) both treatments combined.

METHODS: Randomized block design includes six treatments, two variants of each treatment, and four replications of each. Treatments include controls, 30- and 50-lb. applications of 8-8-8, some applied once only, others every other year. Half of the trees will be sprayed with 3 percent BHC in fuel oil (Feb.-May-July), and half will remain unsprayed.

ASSIGNMENT: Barry F. Malac, Director.

13.—8. SEED ORCHARD MANAGEMENT. 154.4. *Pinus elliottii.*

OBJECT: To test various spacing in slash pine seed orchards.

METHODS: Spacing under tests include 20x20, 30x30, and 40x40-foot spacings.

ASSIGNMENT: Robert L. Koenig, Research Forester.

14. UNITED STATES FOREST SERVICE, FOREST PRODUCTS LABORATORY
Madison, Wisconsin

14—1. WOOD QUALITY EVALUATIONS FOR GENETICS STUDIES. 151.32, 251.32. General.

OBJECT: To provide over-all evaluations of density and fiber characteristics in wide samplings such as Forest Surveys to assist in determining individual tree variations and outstanding or superior wood quality.

METHODS: Specific gravity, summerwood percentages, and fiber characteristics were determined in cooperation with genetics and silvicultural studies at various research projects of the Forest Experiment Station. Wood quality evaluations are being carried out in connection with the Forest Survey in many states in the south and southeastern United States.

COOPERATORS: Southern, Southeastern, Lake States, and Pacific Northwest Forest Experiment Stations, U. S. Forest Service.

ASSIGNMENT: M. Y. Pillow, Supervisory Technologist.

15. UNITED STATES FOREST SERVICE, REGION 8
Atlanta, Georgia

15—1. **Improvement of forest tree seed.** 122.0, 122.1. *Pinus.*

OBJECT: To provide sufficient seed for reforestation needs from the best geographic and parental sources.

METHODS: The tree improvement program will be divided into three phases of activity. The first phase will be the establishment of about 3,100 acres of seed production areas; the second phase will be the establishment of about 1,200 acres of seed orchards; and the third phase, the incorporation of tree improvement principles in silvicultural practices. Work on all three phases will be done concurrently.

ASSIGNMENT. Thomas F. Swofford, Forester.

16. UNITED STATES FOREST SERVICE, SOUTHEASTERN FOREST EXPERIMENT STATION
Asheville, North Carolina

16—1. **Species trials and arboreta.** 111.0, 211.0. General.

OBJECT. To test the performance of several different species planted in arboreta or planting trials.

METHODS: Several different coniferous species were planted during the 1920's on a burned area on Mount Mitchell, North Carolina, and several species were planted in an arboretum on the Bent Creek Experimental Forest. Several hardwood species were planted in different locations in the Piedmont region of North Carolina. This project is now inactive.

ASSIGNMENT: Earl R. Sluder, Associate Silviculturist.

16—2. **Rust tests with pines.** 111.0, 151.5. *Pinus.*

OBJECT: To determine response of *Pinus* species to fusiform rust infection.

METHODS: Eighteen species of hard pines, including several exotics, are being inoculated with specific, single-gall collections of *Cronartium fusiforme.* Pine seedlings are artificially inoculated and disease development is observed under greenhouse conditions. The two primary collections of rust used in the study were from the same loblolly pine plantation, but one gall was cerebroid, while the other was fusoid in shape. These rust collections were found to be distinct serologically, with the cerebroid type being more closely related to *C. quercuum* than to other *C. fusiforme* collections.

ASSIGNMENT: H. R. Powers, Jr., Plant Pathologist.

16—3. **Eastern hemlock seed source study.** 111.1. *Tsuga canadensis.*

OBJECT: To assist the Connecticut Agricultural Experiment Station in a large study.

METHODS: Twenty sources are represented in the outplanting, which consists of two blocks of 16 plots each. Fourteen of the plots in each block consist of a single seed source each, while two plots consist of several sources each. Each plot contains 16 trees planted 6 x 6. Plots are randomized within blocks. Twelve of the plots in each block are Latin squares of four seedlings from four mother trees of the source involved. Seedlings were planted in 1957 on the Pisgah Ranger District near Brevard, North Carolina.

COOPERATOR: Connecticut Agricultural Experiment Station.

ASSIGNMENT: Earl R. Sluder, Associate Silviculturist.

16—4. **White pine seed source study.** 111.1. *Pinus strobus.*

OBJECT: To determine type and extent of racial variation in white pine.

METHODS: This is a range-wide study being conducted by several Forest Experiment Stations and the Ontario Department of Lands and Forests. Sixteen seed sources are being used. The Asheville project's outplantings were made in 1959, except one source, which was planted in 1960. Outplantings consist of four randomized blocks; each plot consists of 81 trees from a seed source planted 7 x 7 in nine rows of nine trees. There are three outplantings: one of all 16 sources in a river bottom (Davidson River) near Brevard, N. C.; one of six sources on old field sites near Nottely Lake near Blairsville, Georgia; and one of six sources in a stream bottom near Wytheville, Virginia. Initial survival counts were made in June 1959; survival was 95 percent for the North Carolina outplanting, 79 percent for the Georgia outplanting, and 85 percent for the Virginia outplanting.

COOPERATORS: Ontario Department of Lands and Forests; The Lake States, Central States, and Northeastern Forest Experiment Stations of the U. S. Forest Service.

ASSIGNMENT: Earl R. Sluder, Associate Silviculturist.

16—5. WHITE PINE AS AN INDICATOR OF AIR POLLUTION. 111.3. *Pinus strobus.*

OBJECT: To determine utility of individual white pine trees as indicators of kind and concentration of air pollutants.

METHOD: Grafts or open-pollinated seedlings of white pine from several locations in Tennessee, North Carolina, West Virginia, and Pennsylvania are exposed in areas where damage from air pollution is thought to occur. Seedlings or grafts or susceptible trees are exposed in different geographic locations and symptoms compared. Grafts of trees known to be good indicators have been planted on the Bent Creek Experimental Forest near Asheville, N. C., and at two locations along the Blue Ridge Parkway.

ASSIGNMENT: Charles R. Berry, Plant Pathologist.

16—6. YELLOW-POPLAR SEED SOURCE STUDY. 211.1. *Liriodendron tulipifera.*

OBJECT: To determine if geographical races of yellow-poplar exist and, if they do exist, which region is best suited as a source of seed for the Southern Appalachians.

METHOD: Trees from 16 seed sources were planted in 1954 in two randomized blocks on the Bent Creek Experimental Forest. Each plot consists of 64 trees from a source, planted 8 x 8. Height and survival were measured for the first 5 years. In 1958, frequent measurements were made to determine the pattern of seasonal height growth.

ASSIGNMENT: Earl R. Sluder, Associate Silviculturist.

16—7. GEOGRAPHIC VARIATION OF NORTHERN RED OAK. 211.1. *Quercus borealis.*

OBJECT: To study variation in northern red oak seedlings from six widely distributed geographic locations.

METHODS: The seedlings, which were furnished by the Cabot Foundation, were planted in 1953 on the Bent Creek Experimental Forest. They were cut off near the ground at the beginning of the 1954 and 1955 growing seasons. Regrowth was measured at weekly intervals during these two seasons and the data sent to the Cabot Foundation. The Foundation has since dropped the study. The planting at Bent Creek is being maintained and the study carried on an informal basis.

ASSIGNMENT: Earl R. Sluder, Associate Silviculturist.

16—8. YELLOW-POPLAR 1-PARENT PROGENY TEST. 211.3. *Liriodendron tulipifera.*

OBJECT: To obtain basic information on variation among 1-parent progenies of yellow-poplar.

METHODS: Seeds were collected in western North Carolina from 8 trees selected for various phenotypic characteristics, kept separate by tree, and sown in a nursery. The 1-0 seedlings were planted in spring 1961 on cleared forest land. Seedbed germination, percent of seedlings under plantable size, and outplanting survival varied by mother tree. Phenotypic observations will be made on the progeny groups to determine differences among them and variation within them. Progeny phenotypes will be compared with parent tree phenotypes.

COOPERATOR: Tennessee Valley Authority, Norris, Tennessee.

ASSIGNMENT: Earl R. Sluder, Associate Silviculturist.

16—9. Inheritance of stem form. 211.3. *Prunus serotina.*

OBJECT: To determine whether stem form, particularly crook and sweep, is inherited in some black cherry trees.

METHODS: A 1-parent progeny test was started in 1964. Seed was collected from five black cherry trees in each of three stem-form categories: (1) straight, (2) moderate crook and sweep, and (3) heavy crook and sweep. Stem crook and sweep were quantified by measuring the right-angle distance from a straight pole to the tree edge at the point of greatest departure from a straight line at each crook and sweep area. Clones of each tree will be propagated and grown with seedling progeny.

ASSIGNMENT: Earl R. Sluder, Associate Silviculturist.

16—10. Northern red oak seedling grades. 211.3. *Quercus borealis.*

OBJECT: To determine the effect of seedling grade on survival and growth of northern red oak seedlings.

METHODS: Three seedling grades, determined by size at the root collar, are being tested in replicated plots on good, average, and poor sites. The overstory and competing brush was deadened during the summer prior to winter planting.

ASSIGNMENT: C. E. McGee, Project Leader.

16—11. Variation in oak to Nectria canker. 211.3, 251.5. *Quercus alba.*

OBJECT: To determine response to infection by *Nectria galligena* of clonal lines of *Quercus alba.*

METHODS: Clonal lines of *Q. alba* were developed from two parental trees, one showing extreme susceptibility, and the second apparent resistance, to Nectria canker. Artificial inoculations will be made to evaluate resistance of these clones as well as that of a group of white oak seedlings from randomly selected seed.

ASSIGNMENT: H. R. Powers, Jr., Plant Pathologist.

17. UNITED STATES FOREST SERVICE, SOUTHEASTERN FOREST EXPERIMENT STATION

Athens, Georgia

17—1. Pine species comparison test. 111.0. *Pinus* spp.

OBJECT: To compare adaptability of the species for planting on Piedmont clay soils.

METHODS: Tests established in 1957 consist of plots of 121 trees, one plot of each species, replicated three times at different locations. Loblolly, shortleaf, longleaf, slash, white, and Virginia pine plantings are located at Calhoun Experimental Forest in Piedmont South Carolina.

ASSIGNMENT: R. G. McAlpine, Project Leader.

17—2. Selection and breeding of littleleaf-resistant pine. 111.1, 111.3, 112.02. *Pinus echinata.*

OBJECT: (1) The development of littleleaf-resistant strains of shortleaf pine, and (2) searching for littleleaf-resistant strains of shortleaf pine from within the natural geographic range of the species.

METHODS: Apparent littleleaf-resistant shortleaf pine are being selected on severe littleleaf sites. Scions collected from these selections have been grafted to shortleaf pine stock and outplanted in 1953 and 1954. Twenty-one clones, 10 to 20 individuals each, planted in rows, are represented in an outplanting area at Athens, Georgia. Open-pollinated progeny have been subjected to tests for resistance under experimentally intensified littleleaf conditions. Georgraphic seed source plantings include seed lots of 12 sources planted in 2 blocks of 12 plots each with 48 trees in each plot. The plantings are located in Athens, Georgia; the Calhoun Experimental Forest, Union, South Carolina; and the Lee Experimental Forest, Virginia.

COOPERATOR: School of Forestry, University of Georgia, Athens.

ASSIGNMENT: W. C. Bryan, Pathologist.

17—3. TEST OF SONDEREGGER PINE IN THE PIEDMONT. 112.01. *Pinus × sondereggeri.*

OBJECT. To test performance of a natural hybrid in the Piedmont.

METHOD: This is an informal study consisting of four plantings of 50 to 100 trees each of Sonderegger pine selected from seedbeds at the South Carolina State nursery at Wedgefield. Plantings located on Calhoun Experimental Forest in the Piedmont of South Carolina.

ASSIGNMENT: R. G. McAlpine, Project Leader.

17—4. PROGENY TEST FOR RESISTANCE TO LITTLELEAF. 112.02, 112.03. *Pinus echinata.*

OBJECT: To determine inheritance to littleleaf disease in shortleaf pine progeny from different parental matings.

METHODS: Seedlings obtained from selfing and crossing clones of shortleaf pine located at Athens, Georgia, were planted in April 1965 on a 6-acre area on the Calhoun Experimental Forest, Union, South Carolina. Thirty-four progeny group plus a check, or a total of 700 trees, were planted. The test design is five randomized blocks with four trees per plot. The isolation strip around the entire test area was planted with run-of-the-mill seedlings. The area is surrounded by shortleaf pine in all stages of the disease.

ASSIGNMENT: W. C. Bryan, Pathologist.

17—5. SELECTION CATALOGUE FOR HARDWOODS. 211.3. Hardwoods.

OBJECT: To locate, describe, and catalogue individual hardwood trees that exhibit characteristics useful in a forest genetics and tree improvement program.

METHODS: The selections will be based primarily on traits such as superior tree and wood quality, form, growth rate, and other desirable characteristics. Some trees with undesirable characteristics will be catalogued. A description and location form is given. A numbering system for trees is described and code numbers for 46 hardwood tree species assigned.

ASSIGNMENT: R. G. McAlpine, Project Leader; C. D. Webb, Plant Geneticist.

176—6. PARENT AND SEEDLING GRADE EFFECTS IN SWEETGUM. 211.3. *Liquidambar styraciflua.*

OBJECT: To determine (1) the relationship between morphological grades of seedlings and subsequent survival and early growth, and (2) if maternal parent has any effect on survival and growth, leaf coloration, branching habit, bud formation, and bark characteristics.

METHODS: Seedlings from a study at Macon, Georgia, of seedbed density effects were graded by root collar diameters into four classes. Seedlings from 10 open-pollinated parent trees were planted in spring of 1964 on a prepared bottomland site along the Oconee River in Greene County, Georgia. The experiment is a split-plot factorial in a randomized block design. Plots consist of 25 measurement trees at a spacing of 6 x 6 surrounded by a 24-tree isolation row of the same parentage and seedling grade.

ASSIGNMENT: R. G. McAlpine, Project Leader; C. D. Webb, Plant Geneticist.

17—7. SYCAMORE SEEDLING GRADES. 211.3. *Platanus occidentalis.*

OBJECT: To determine (1) the feasibility of underplanting seedlings with immediate and complete overstory control; (2) find an optimum size of seedling stock for underplanting; and (3) the necessity for cleanings to remove understory competition.

METHODS: Five grades of 1-year sycamore seedlings will be underplanted in a hardwood stand of poor composition in a Piedmont creek bottom subject to periodic flooding. Grades of seedlings based on root collar diameters are 3/20, 4/20, 5/20, 6/20, and 7/20 inch. These will be planted at a spacing of 6 x 6 in 10 plots in each of two randomized complete blocks. One plot of each grade will be cleaned as necessary to release seedlings from understory competition.

ASSIGNMENT: R. G. McAlpine, Project Leader; C. D. Webb, Plant Geneticist.

17—8. VEGETATIVE PROPAGATION METHODS. 251.02. *Liriodendron tulipifera, Liquidambar styraciflua.*

OBJECT: (1) To develop techniques for year-around rooting of cuttings from hardwood trees, primarily yellow-poplar and sweetgum; (2) to determine the effect of tree age and time of taking cuttings on rooting ability; (3) to find if differences exist between rooting ability of cuttings taken from the tree crown, epicormic branches, and stump sprouts; and (4) to find if differences in rooting exist between hardwood and softwood cuttings.

METHODS: Greenhouse facilities will be used. Individual studies will be designed to attain various parts of the objectives. The most promising treatments with growth regulators and environments will be used initially.

ASSIGNMENT: R. G. McAlpine, Project Leader.

18. UNITED STATES FOREST SERVICE, SOUTHEASTERN FOREST EXPERIMENT STATION

Blacksburg, Virginia

18—1. SPECIES COMPARISON OF CERTAIN SOFTWOODS AND HARDWOODS. 111.0, 211.0. *Pinus taeda, P. echinata, P. virginiana, P. strobus, Juniperus virginiana,* and *Liriodendron tulipifera.*

OBJECT: To determine adaptability of certain species to planting in the Piedmont of Virginia.

METHODS: In 1945, Virginia, shortleaf, white, and loblolly pine plus redcedar were each planted on good and poor abandoned fields. There were five replications on each site with 242 trees per plot spaced 6 x 6. Only two plots of yellow-poplar were planted.

ASSIGNMENT: Jack Stubbs, Project Leader.

18—2. SEED SOURCE OF LOBLOLLY PINE. 111.1. *Pinus taeda.*

OBJECT: To determine the effect of geographic seed source on the growth and development of loblolly pine in the Virginia Piedmont.

METHODS: Study was established in 1945. It is a replicated block experiment with five blocks of four plots each—one plot for each of four sources. Plots are 1.36 x 0.72 chains and contain 8 rows of 15 trees each, planted 6 x 6. Sources represented are Arkansas, Mississippi, South Carolina, and North Carolina. This installation is on the Lee Experimental Forest 4 miles south of Buckingham, Virginia. The plantings are on abandoned old fields.

ASSIGNMENT: Jack Stubbs, Project Leader.

18—3. SEED SOURCE OF SHORTLEAF PINE. 111.1. *Pinus echinata.*

OBJECT: To determine the effect of geographic seed source on the growth and development of shortleaf pine in the Virginia Piedmont.

METHODS: Study was established in 1945. It is a replicated block experiment with five blocks of six plots each—one plot for each of six sources. Plots are 1.36 x 0.72 chains, and contain 8 rows of 15 trees each, planted 6 x 6 feet. Sources are Arkansas, Mississippi, Alabama, Virginia (planted 1949), Ohio, and New Jersey. This installation is on the Lee Experimental Forest, 4 miles south of Buckingham, Virginia. The plantings are on abandoned old fields.

ASSIGNMENT: Jack Stubbs, Project Leader.

18—4. SELECTION AND TESTING OF VARIATION. 111.3. *Pinus virginiana.*

OBJECT: To determine variation and inheritance of economically important traits and isolate superior types.

METHODS: A catalogue of superior phenotypes and a rating method have been set up. In 1962, selection and progeny testing began of 20 pairs of trees having similar ages, diameters, heights, and competition. One tree of each pair shows good pruning ability and the other one poor pruning ability. The studies are located on the Lee Experimental Forest near Buckingham, Virginia.

ASSIGNMENT: Jack Stubbs, Project Leader; D. L. Bramlett and J. G. Hutchinson, Research Foresters.

18—5. Flowering characteristics in certain pines. 151.0 *Pinus echinata, P. virginiana.*

OBJECT: To determine importance of environmental factors in flower induction, pollination, seed development, seed production, and seed predators in the Piedmont of Virginia.

METHODS: Annual variation in flower, conelet, and seed production is being observed. Development records are being kept from the strobilus to the mature cone. The effects of different soil moisture levels on the production of female flowers in shortleaf pine are being determined. The studies are located on the Lee Experimental Forest near Buckingham, Virginia.

ASSIGNMENT: Jack Stubbs, Project Leader; D. L. Bramlett, Research Forester.

19. UNITED STATES FOREST SERVICE, SOUTHEASTERN FOREST EXPERIMENT STATION

Charleston, South Carolina

19—1. A test of species suitable for Sandhills planting. 111.0. *Pinus, Juniperus, Cupressus.*

OBJECT: To test survival and early growth of various conifers native to adverse sites for planting in the Sandhills.

METHODS: Species tested are native of either very wet or very dry sites in about the same climatic region as the Sandhills. Plots of 50 trees of each species replicated three times were established for three consecutive years, 1955 through 1957, although species changed somewhat from year to year. Species planted are: loblolly, slash, longleaf, pond, shortleaf, Virginia, spruce, sand, lodgepole, and jack pines, eastern redcedar, Arizona cypress.

Plantings located on Manchester State Forest, South Carolina.

COOPERATOR: South Carolina Commission of Forestry.

ASSIGNMENT: O. Gordon Langdon, Project Leader.

19—2. Growth of pines from Spain. 111.0. *P. halepensis, P. laricio, P. pinaster,* and *P. pinea.*

OBJECT: To determine growth and other performance characteristics of four species of pine from Spain planted on sandhill soil.

METHODS: Twenty-five seedlings of each species were planted in five rows of five seedlings each on the Manchester State Forest in South Carolina. Location is in an old field.

COOPERATOR: South Carolina Commission of Forestry.

ASSIGNMENT: O. Gordon Langdon, Project Leader.

19—3. Comparison of pine species. 111.0. *Pinus palustris, P. serotina, P. elliottii,* and *P. taeda.*

OBJECT: To compare survival and growth of four pine species planted on a wet, savannah site in South Carolina.

METHODS: The area was burned before planting. The planting design was two Latin squares with plots 60 feet square and tree spacing 6 x 6. No grade 3 seedlings were used. The innermost 7 x 7 rows of trees were measured.

COOPERATOR: South Carolina National Forest.

ASSIGNMENT: O. Gordon Langdon, Project Leader.

19—4. Species comparison on bottomland sites. 111.0, 211.0. *Pinus glabra, P. taeda, Juniperus virginiana, Quercus falcata* var. *pagodaefolia, Q. prinus, Q. shumardii, Liriodendron tulipifera,* and *Liquidambar styraciflua.*

OBJECT: To compare survival and growth of certain hardwoods and conifers planted on representative good sites in typical rundown stands of bottomland hardwood in South Carolina.

METHODS: The variables are: (1) species, five hardwood and three conifers; (2) sites, first bottom and terrace; (3) treatment, release and no release; (4) replication in space, each species, site and treatment combination replicated twice; and (5) replication in time, 3 years from 1953 through 1955. Each plot is 24 x 24 with 100 seedlings spaced 2 x 2. For growth comparisons plots are to be thinned to a 4 x 4-foot spacing. Each site subplot has a 25-foot isolation strip.

ASSIGNMENT: O. Gordon Langdon, Project Leader.

19—5. COMPARISON OF SAND PINE WITH OTHER PINES IN SANDHILL PLANTINGS. 111.0, 111.1. *Pinus clausa, P. elliottii, P. taeda, P. palustris.*

OBJECT: To determine survival and early growth of two sand pine races in comparison with other pines planted on sandhill soils in west Georgia and South Carolina.

METHODS: Seedlings of the Ocala and Choctawhatchee races of sand pine plus slash, longleaf, and loblolly seedlings were planted in Talbot County, Georgia, in February 1964. Spacing was 6 x 6 in plots 84 feet square in a split-plot Latin square. Oak sprouts on one of the subplots will be allowed to grow, those on the other will be eradicated. An additional planting was made during February 1964 in the Sandhills State Forest, Chesterfield County, South Carolina.

COOPERATORS: Georgia Kraft Company; South Carolina Commission of Forestry.

ASSIGNMENT: O. Gordon Langdon, Project Leader.

19—6. TEST OF LOCAL LONGLEAF PINE SEED SOURCE. 111.1. *Pinus palustris.*

OBJECT: To test growth and survival of longleaf seedlings from eight seed sources in north Georgia, South Carolina, and southern North Carolina when planted in the South Carolina Sandhills.

METHODS: Seedlings were planted in 1955 through 1957 at the Sandhills State Forest and the Manchester State Forest. Each location contains plots of 121 trees planted 6 x 6 for each seed source, replicated four times. Three annual replications were established with seed from the same general sources but from different trees. The seed sources: Augusta, Georgia; Aiken, Jasper, Horry, Berkeley, and Richland Counties, South Carolina; Francis Marion National Forest, Manchester and Sandhills State Forests, South Carolina; Bladen Lakes State Forest, North Carolina. Test plantings are located on deep sand sites.

COOPERATOR: South Carolina Commission of Forestry.

ASSIGNMENT: O. Gordon Langdon, Project Leader.

19—7. LONGLEAF PINE SEEDLING GRADES. 111.3. *Pinus palustris.*

OBJECT. To determine the effect of seedling grade, foliage clipping, root pruning, and season of planting on longleaf survival when planted on cleared sandhill sites.

METHODS: One-year-old longleaf pine seedlings from the Wedgefield, South Carolina, nursery were used. Plantings were made in the Manchester and Sandhills State Forest in South Carolina. Outplanting was done in the fall of 1953, the winter of 1954, and spring of 1954. Number 1 and number 2 grade stock were used. Treatment of seedlings consisted of needles clipped to 5 inches and roots pruned 3, 5, and 7 inches and needles not clipped and roots pruned to 3, 5, and 7 inches. Four blocks were laid out at each location. Each block was divided into three seasonal treatments and each seasonal treatment was further divided in 24 rows 100 feet long. Rows are 6 feet apart and trees are spaced 4 feet apart within rows.

COOPERATOR: South Carolina Commission of Forestry.

ASSIGNMENT: O. Gordon Langdon, Project Leader.

19—8. GROWTH OF SUPERIOR VERSUS AVERAGE NURSERY SELECTED PINE SEEDLINGS. 111.3. *Pinus palustris, P. taeda,* and *P. elliottii.*

OBJECT: To determine whether the initial vigor of extra large seedlings selected from nursery beds is carried through subsequent years as a genetically controlled characteristic.

METHODS: Plots contain 12 trees, planted 6 x 6 feet. There is one plot of superior seedlings and one plot of average seedlings of each species with two replicates planted each year for 4 years, 1952 to 1955. Plots are located on a flatwoods site at the Santee Experimental Forest.

ASSIGNMENT: O. Gordon Langdon, Project Leader.

19—9. TUPELO ECOTYPES. 211.0, 211.1. *Nyssa aquatica, Nyssa sylvatica* var. *biflora*.

OBJECT: To determine effects of saturated and flooded soil conditions on the growth, anatomy, and morphology of swamp tupelo and water tupelo from three seed ecotypes.

METHODS: One-year-old seedlings are grown in tanks under six water regimes of flooded and saturated soils for one growing season. The experiment is laid out as a 6 x 6 Latin square and will be replicated twice in time (years). Water tupelo seedlings are being used from two seed sources in each of the three ecotypes: red river, black river, and nonalluvial swamp, and swamp tupelo seedlings from two seed sources in each of three ecotypes: pond, black river, and nonalluvial swamp. The soil tanks are on the Santee Experimental Forest in South Carolina.

ASSIGNMENT: O. Gordon Langdon, Project Leader.

19—10. HYBRID POPLARS. 212.02. *Populus*.

OBJECT: To determine growth of five hybrid poplar clones on the Santee Experimental Forest in South Carolina.

METHODS: Five cuttings of each clone were treated with rootone and placed in the soil so that only two buds were above the ground line. The area was a good hardwood site and the cuttings were cultivated during the first growing season. The cuttings were furnished by personnel of the Westvaco Experimental Forest in South Carolina.

COOPERATOR: West Virginia Pulp and Paper Company.

ASSIGNMENT: O. Gordon Langdon, Project Leader.

20. UNITED STATES FOREST SERVICE, SOUTHEASTERN FOREST EXPERIMENT STATION
Cordele, Georgia

20—1. EFFECT OF CLIMATIC AND ENVIRONMENTAL FACTORS ON WOOD PROPERTIES OF PLANTED SLASH PINE. 111.2, 151.08, 151.32. *Pinus elliottii*.

OBJECT: To determine (1) factors for use in converting cubic-foot yields in slash pine plantations to pounds of usable woods, and (2) measurable factors which influence wood density, both climatic and environmental.

METHODS: Increment cores were obtained from slash pine trees over an area of 37 counties in southern Georgia. The stands were the same as those used for a study of yields in relation to age, site, and density. Increment cores were collected at d.b.h. from dominant and codominant trees. Broad specific gravity was determined by the maximum moisture content method. Increment cores were dissected into 5-year increments starting from the bark. Summerwood percent was obtained by means of a binocular instrument. All independent variables, (site index, stand density, age, growing-season rainfall, and summer rainfall) are being plotted individually and in pairs under the dependent variables specific gravity and percent summerwood in order to identify any independent variables that are not correlated with the dependent ones, and, also, to help in determining any trend toward curvilinearity and possible interactions. Multiple regressions are being used to determine the extent of correlation of the remaining variables.

ASSIGNMENT: Frank A. Bennett, Project Leader.

20—2. CATALOGUE OF SELECTED TREES. 111.3. *Pinus elliottii*.

OBJECT: To locate, label, describe, and catalogue plus slash pine within plantations.

METHODS: Starting in 1953, outstanding trees on the George Walton Experimental Forest have been described on a standard form. Volume growth is compared with adjacent trees. Summerwood proportion of the increment core is indicated on a diagram, based on ocular examination.

ASSIGNMENT: Frank A. Bennett, Project Leader.

20—3. INHERITANCE OF TRAITS IN SLASH PINE. 111.3. *Pinus elliottii.*

OBJECT: To determine the extent to which maternal parent trees with certain traits may transmit their qualities to progeny.

METHODS: Seedlings for the study were planted in February 1956 on an old field near Cordele, Georgia. Progeny were included of two trees in each of four form groups as follows: (1) good form, (2) pronounced crook, (3) forked, and (4) pronounced taper. Two rows of 25 trees each were planted at a spacing of 10 x 10. An additional row of 25 trees from each maternal parent was planted adjacent to the main planting.

ASSIGNMENT: Frank A. Bennett, Project Leader.

21. UNITED STATES FOREST SERVICE, SOUTHEASTERN FOREST EXPERIMENT STATION

Fort Myers, Florida

21—1. COMPARATIVE GROWTH OF PINES IN SOUTH FLORIDA. 111.0. *Pinus palustris, P. elliottii* var. *elliottii, P. elliottii* var. *densa, P. taeda.*

OBJECT: To determine survival and growth of loblolly, longleaf, and two varieties of slash pine in south Florida.

METHOD: Seedlings of loblolly, longleaf, and typical slash pine were obtained from Olustee and Munson nurseries in Florida. South Florida slash pine seedlings were all from the Keri Nursery of the Alico Land Development Company, the only available source. Four outplantings were located on each of the east and west coasts of southern Florida. Each plot contained 7 x 7 rows of seedlings spaced 8 x 8. There are four replications.

COOPERATION: Alico Land Development Company; Florida Forest Service.

ASSIGNMENT: J. W. McMinn, Associate Silviculturist.

21—2. SEED SOURCE OF SOUTH FLORIDA SLASH PINE. 111.1. *Pinus elliottii* var. *densa.*

OBJECT: To determine the effects of seed source, seed size, and seedling size in South Florida slash pine.

METHODS: Seed from Hendry County, in the south-central portion of the variety's range, and Polk County, near the northern limit of the natural distribution, are compared. Seed was divided into medium and large, and seedlings into small, medium, and large. The outplanting area is in Charlotte County. The trees were planted with a spacing of 6 x 7 in a randomized block design with four replications. Each plot contained 7 x 7 rows of trees.

ASSIGNMENT: J. W. McMinn, Associate Silviculturist.

22. UNITED STATES FOREST SERVICE, SOUTHEASTERN FOREST EXPERIMENT STATION

Franklin, Virginia

22—1. INHERITANCE OF FORM. 111.3. *Pinus taeda.*

OBJECT: To determine effect of cone characters and seed tree form on loblolly pine cone collections in coastal Virginia.

METHODS: Cones were collected from 29 loblolly pine trees in October 1952. Seed were extracted, stratified, and planted beneath Hot Caps March 23, 1953. Spacing was 8 x 8. The resulting planting contains 450 seed spots in a block with two rows of 8 x 8-foot spaced trees as a margin. The planting was on the Camp Experimental Forest in Sussex County, Virginia. The soil is Atlee very fine, sandy loam. Previous to planting, the field was in corn. The plantation contains seedlings from each of six trees classed as one of five classes of parent trees. Tree classes are forked, good, upswept branches, rough, and residual trees left following clearcutting. The basic plot contains six rows of five seedlings. Each row was from a single tree and the plot was of one class of trees. Each plot was replicated three times.

ASSIGNMENT: K. B. Trousdell, Silviculturist.

23. UNITED STATES FOREST SERVICE, SOUTHEASTERN FOREST EXPERIMENT STATION
Macon, Georgia

23—1. Growth and tree quality characteristics of minor southern pines and certain exotics. 111.0. *Pinus.*

OBJECT: To determine some of the characteristics of minor species so they can be used effectively in hybridization programs.

METHODS: Seedlings of sand, spruce, pond, and Virginia pine were planted in middle Georgia. Other pines from eastern United States such as pitch and Table-Mountain pine are included. Rate of growth and other data related to tree form and resistance to pests will be recorded. The purpose is to obtain information now lacking about minor species so that they may be used, if feasible, for hybridization with major southern pines or other species.

COOPERATORS: Georgia Kraft Company; Georgia Forest Research Council.

ASSIGNMENT: John F. Kraus, Plant Geneticist.

23—2. Racial variation in loblolly pine in Georgia. 111.1. *Pinus taeda.*

OBJECT: To determine the kind and amount of racial variation in loblolly pine throughout the State of Georgia and adjacent areas of Florida.

METHODS: Seed was obtained from 14 locations throughout Georgia and 3 in north Florida in 1955. Also, one seed lot from south Arkansas (Crossett) was obtained. Seedlings were outplanted at ten locations in Georgia and one in Florida. Six plantations in Georgia have all 18 seed lots represented, two have 15, and two have 13. Each plantation has four replications and 36 trees per plot. Survival and height measurements have been taken at 1, 2, 3, and 5 years. Fusiform rust and tipmoth damage were recorded at 3 and 5 years.

COOPERATORS: Georgia Forestry Commission; several pulp and paper companies; Georgia Forest Research Council.

ASSIGNMENT: John F. Kraus, Plant Geneticist; T. LaFarge, Research Forester.

23—3. Stand variation in loblolly pine. 111.1, 111.2, 111.3. *Pinus taeda.*

OBJECT: To estimate the variation between trees in loblolly pine stands and the influence of number of trees on accuracy of stand samples in racial selection studies.

METHODS: From the seed collected in 1955 for project 23—2 above, seed was kept separate by 11 maternal parents on each of three acres. One area was in southeast Georgia, one in middle Georgia, and one in northwest Georgia. All seedlings were outplanted in middle Georgia in 25-tree plots with 4 replications. Survival, growth, and disease and insect attack were recorded at 1, 2, 3, and 5 years of age.

COOPERATORS: Georgia Kraft Company; Georgia Forestry Commission; Georgia Forest Research Council.

ASSIGNMENT: John F. Kraus, Plant Geneticist; T. LaFarge, Research Forester.

23—4. Shoot growth phenology of loblolly pine from several geographic sources and open-pollinated progenies within sources. 111.1, 111.3. *Pinus taeda.*

OBJECT: To determine patterns of height growth in loblolly pine from several geographic sources, and among progenies within sources.

METHODS: In the Bleckley County plantation of the local loblolly racial test described in project 23—2 above, five trees were randomly chosen from each of four replications of six seed sources. Weekly measurements of terminal shoot elongation were made during the 1962 growing season. In the adjacent plantation of the loblolly stand variation study described in project 23—3 above, three trees were randomly chosen from each of four replications of three progenies of each of the three sources. Weekly measurements of terminal shoot elongation were made during the 1962 growing season. Correlations among growth pattern (date, rate, duration, etc.) and total height, height growth, and fusiform rust incidence will be examined.

COOPERATORS: Georgia Kraft Company; Georgia Forest Research Council; Georgia Forestry Commission.

ASSIGNMENT: John F. Kraus, Plant Geneticist.

23—5. CROWN FORM OF LOBLOLLY PINE FROM ARKANSAS. 111.1, 111.3. *Pinus taeda.*

OBJECT: To compare crown form of open-pollinated loblolly pine progeny of plus trees growing in Arkansas with progeny of certain selected loblolly pines growing in Georgia.

METHODS: In the spring of 1960, progeny of three outstanding loblolly pine in Arkansas were planted with those of three Georgia trees in a 6 x 6 Latin square with 4 trees per plot at 10 x 10 spacing. Branch diameter and length will be measured to permit a more accurate comparison of form among trees than is possible to obtain in racial variation studies of the Crossett, Arkansas, race.

COOPERATOR: Southern Forest Experiment Station, Crossett, Arkansas.

ASSIGNMENT: John F. Kraus, Plant Geneticist.

23—6. SHORTLEAF RACES CROSSED WITH SLASH PINE. 111.1, 112.01. *Pinus echinata, P. elliottii.*

OBJECT: To compare various races of shortleaf pine crossed with one race of slash pine combinations with each other and with slash and shortleaf pine in terms of survival, cold resistance, drought resistance, growth rate, resistance to fusiform rust, recovery from tipmoth damage, and susceptibility to littleleaf disease, at suitable locations throughout the range of shortleaf pine and portions of the natural and artificially extended range of slash pine.

METHODS: In January 1964, an installation of the "Cooperative Study of Shortleaf Geographic Races X Slash Pine (IG-12.6)" was planted near Allentown, Georgia. The plantation was installed in accordance with the study plan, dated September 27, 1963, provided by the Institute of Forest Genetics at Gulfport, Mississippi. Six shortleaf x slash hybrids and five checks (two slash, three shortleaf) were planted in row plots of 15 trees in six randomized blocks. This plantation is being shown as a separate study because additional checks were included besides those called for in the study plan. Also, the plantation is adjacent to other progeny tests which may permit rough comparisons of performance of the hybrids. The planting site has a history of severe fusiform rust and tipmoth infections, and provides an especially good location to test the hybrids.

COOPERATORS: Institute of Forest Genetics at Gulfport; Georgia Kraft Company.

ASSIGNMENT: John F. Kraus, Plant Geneticist.

23—7. BREEDING SOUTHERN PINES FOR DESIRABLE TRAITS. 111.3, 112.01, 112.02, 14, 153, 151.32. *Pinus taeda, P. elliottii, P. echinata,* and *P. palustris.*

OBJECT: To breed improved strains, for planting locally, of the major southern softwoods through intraspecific and interspecific hybridization.

METHODS: Selection of superior phenotypes with combinations of good traits was carried out in natural stands and plantations near Macon and Cordele. A few poor phenotypes were included for comparison. Germ plasm of most selected trees is preserved by grafting. One-parent progeny tests of slash, longleaf, shortleaf, and loblolly pine have been established. Row or rectangular plots replicated several times have been used. Progeny of more than 100 maternal parents were planted in 1956 and 1957. A three-phase program involving a "poly-cross" test, individual crosses, and selfing was developed for testing over 300 selections being used in the Georgia Forestry Commission seed orchards. In breeding, emphasis has been on growth rate, tree form, resistance to pests, and wood quality. Disease resistance work is in cooperation with the Division of Forest Protection Research.

COOPERATORS: Georgia Kraft Company; Continental Can Co.; Georgia Forestry Commission; Georgia Forestry Research Council.

ASSIGNMENT: John F. Kraus, Plant Geneticist; T. Miller, Pathologist; T. LaFarge, Research Forester.

23—8. TECHNICAL DIRECTION OF IDA CASON CALLAWAY FOUNDATION TREE BREEDING PROJECT. 111.3, 112.01, 112.02. *Pinus* spp.

OBJECT: To assist the Foundation in the development of improved forest tree strains for planting in west central Georgia.

METHODS: Plans were prepared for overall operation of the tree breeding project. Progeny test data were obtained and analyzed. Recommendations were made for seed orchard establishment. A total of 1,405 plots has been established in 47 individual studies. Small plantings of southern pine species hybrids are included. The first plantings were made in 1951.

COOPERATOR: Ida Cason Callaway Foundation.

ASSIGNMENT: John F. Kraus, Plant Geneticist.

23—9. NURSERY SELECTION. 111.3. *Pinus elliottii, P. taeda,* and *P.* x *sondereggeri.*

OBJECT: To apply nursery selection techniques in tree breeding and to learn something of the advantages as well as disadvantages of the method.

METHODS: Approximately 500 each of slash, loblolly, and Sonderegger pine seedlings averaging twice the height of average seedlings were selected in nursery beds of the Georgia Forestry Commission. They were outplanted in 1954 in a paired planting design. Annual measurements were taken for 4 years. Seedling selection was repeated in 1955 and approximately 100 seedlings each of slash and loblolly pine were planted. Comparisons of height growth, rust infection, survival, and form have been made.

COOPERATORS: Georgia Forest Research Council; Georgia Forestry Commission.

ASSIGNMENT: John F. Kraus, Plant Geneticist.

23—10. PROGENY TESTING SEED ORCHARD CLONES. 111.3, 112.02. *Pinus elliottii, P. taeda.*

OBJECT: To determine the specific combining ability of about 308 clones represented in seed orchards of the Georgia Forestry Commission and to estimate the additive and dominance variation within the clones represented in the orchards.

METHODS: The first pollinations were made in 1958. A modified topcross is being used. In addition, certain individual clones will be crossed and selfed. Randomized blocks and row plantings are being used. Spacing is 8.5 x 8.5 feet.

COOPERATORS: Georgia Forestry Commission; Georgia Forest Research Council.

ASSIGNMENT: John F. Kraus, Plant Geneticist; T. LaFarge, Research Forester.

23—11. SOUTHERN PINE SPECIES HYBRIDS. 112.01. *Pinus* spp.

OBJECT: To determine growth and other traits of hybrids planted in the Georgia Piedmont.

METHODS: Four lots of hybrid material from shortleaf and loblolly crosses and four lots of open-pollinated seedlings all from seed produced at the Institute of Forest Genetics at Placerville, California, were planted in 1951. There are three replications totaling 24 plots in the study.

COOPERATOR: Georgia Forest Research Council.

ASSIGNMENT: John F. Kraus, Plant Geneticist.

23—12. PERFORMANCE TESTS OF CONTROL-POLLINATED SLASH PINE PROGENY WITH IDA CASON CALLAWAY FOUNDATION. 112.02. *Pinus elliottii.*

OBJECT: To determine inheritance of traits in progeny of slash pine selected for a combination of good traits.

METHODS: Thirty-one plots in a replicated design were established near Macon, Georgia, with seedlings from crosses of slash pine trees that were rated highest on the basis of 1-parent tests. A larger planting of similar material was made at the same time on property of the Callaway Foundation which lies some 90 miles west of Macon. Special emphasis is upon resistance to fusiform rust because 1-parent progeny of the parental stock had low percent infection.

COOPERATORS: Ida Cason Callaway Foundation; Georgia Kraft Company.

ASSIGNMENT: John F. Kraus, Plant Geneticist.

23—13. Cone production and seed quality. 154. *Pinus taeda* and *P. elliottii.*

OBJECT: To determine accuracy with which cone crops in seed production areas can be estimated and obtain an estimate of seed quality when produced in a seed production area.

METHODS: Cones were counted with the aid of binoculars prior to ripening and compared with a count of cones after the trees were cut. Relationship between number and size of seed and characteristics of the cones and size of the cone crop were determined.

COOPERATORS: Continental Can Company; Georgia Forest Research Council; Georgia Forestry Commission.

ASSIGNMENT: John F. Kraus, Plant Geneticist.

23—14. Nursery production of sweetgum. 211.3. *Liquidambar styraciflua.*

OBJECT: To determine the effect of nurserybed density and mother-tree on production of plantable seedlings.

METHODS: Seed were collected from 15 randomly chosen sweetgum trees in Oconee and Clarke Counties, Georgia. Seed was sown by individual mother-tree to grow seedlings at densities of 10, 20, 30, and 40 per square foot. Nursery data included height, coloration, branching, weight, root-top ratios and grade yield. Seedlings were outplanted in Bleckley County, Georgia.

COOPERATORS: Georgia Forestry Commission; Georgia Forest Research Council.

ASSIGNMENT: C. D. Webb and John F. Kraus, Plant Geneticists.

24. UNITED STATES FOREST SERVICE, SOUTHEASTERN FOREST EXPERIMENT STATION

Marianna, Florida

24—1. St. Joe species test. 111.0, *Pinus elliottii, P. taeda, P. palustris, P. echinata, P. radiata, P. virginiana, P. clausa.*

OBJECT: To compare early survival and subsequent growth of hand- and/or machine-planted slash, loblolly, longleaf, shortleaf, Monterey, Virginia, and Ocala and Choctawhatchee sand pine on a sandhill site prepared with rootrake, harrow, and undercut.

METHODS: In January 1954 loblolly, slash, shortleaf, longleaf, and Monterey pine were planted 7 feet apart in 18 rows of 125 seedlings. One plot was machine-planted and another bar-planted on a sandhill site in Liberty County, Florida, prepared by rootrake, harrow, and undercut. Virginia, Ocala sand, and Choctawhatchee sand pine were bar-planted in January 1955 on an adjacent, similarly prepared site. Square measurement plots of 49 trees were established in each planting. Annual measurements were taken of surviving species through age 10.

COOPERATOR: St. Joe Paper Co.; Florida Board of Forestry.

ASSIGNMENT: Russell M. Burns, Research Forester.

24—2. Chipola species test. 111.0 *Pinus elliottii, P. taeda, P. palustris, P. clausa.*

OBJECT: To compare the survival, growth, and long-term performance of planted slash, loblolly, longleaf, and Choctawhatchee sand pine on a prepared sandhill site.

METHODS: In January 1959, 1-0 stock of loblolly, slash, longleaf, and Choctawhatchee sand pine was machine-planted on a sandhill site prepared by burning and double chopping with a Marden Duplex Brush Cutter the previous summer. Each species was planted 6 x 8 (908/acre) on plots measuring 300 square feet (2.1 acres). Measurements of total height and survival are taken annually.

COOPERATORS: Florida Board of Forestry; Hardaway Contracting Co.; International Paper Co.

ASSIGNMENT: Russell M. Burns, Research Forester.

24—3. TAXON TRIALS. 111.0, 211.0. Softwoods, hardwoods.

OBJECT: A framework within which exploratory planting trials of available species, races, or hybrids (tree taxa) may be made.

METHODS: From 1960 until 1963 lineal plantings were made of promising and available native and exotic conifers and hardwoods. In 1964 a 7 x 7 grid of trees planted 8 feet apart was substituted. Seedlings have been 1-0 stock hand-planted on sandhill sites cleared of scrub hardwoods and wiregrass by means of a Marden Duplex Brush Cutter.

COOPERATORS: Florida Board of Forestry; International Paper Co.; St. Joe Paper Co.

ASSIGNMENT: Russell M. Burns, Research Forester.

24—4. SAND PINE RACE COMPARISON. 111.1. *Pinus clausa.*

OBJECT: To compare survival, growth, adaptability to site, and resistance to insects and disease of Ocala and Choctawhatchee sand pine planted in the sandhills of northwest Florida.

METHODS: In 1955, and again in 1956, two 9 x 14-tree Choctawhatchee plots and two 9 x 14-tree Ocala sand pine plots (randomly arranged) were bar-planted on each of 4 root-raked sandhill sites on the Chipola Experimental Forest. Spacing approximated 6 x 6. Fail spots in both installations were replanted at the end of the first growing season. Survival, height, and d.b.h. measurements are taken on the center 50 trees.

COOPERATORS: Florida Board of Forestry; Hardaway Contracting Company; International Paper Company.

ASSIGNMENT: Russell M. Burns, Research Forester.

24—5. RESPONSE OF SLASH PINE SEEDLINGS FROM EIGHT SEED SOURCES TO FERTILIZATION. 111.1, 151.03. *Pinus elliottii.*

OBJECT: To determine whether a racial or individual tree variation exists in the nutrient requirements of slash pine, specifically the nitrogen, phosphorus, and potassium requirements of this species.

METHODS: Seed obtained from eight seed sources, two individual trees per seed source, covering the major portion of the natural range of slash pine, was used for this study. Seedlings were grown under greenhouse conditions for one year and fertilized with N, P, K, and Mg. Measurements made of the study material include seedling weight and foliar N, P, K, and Mg by treatments.

COOPERATORS: Florida Board of Forestry.

ASSIGNMENT: R. H. Brendemuehl, Project Leader.

24—6. EVALUATION OF TIP-MOTH INJURY IN RELATION TO TREE GROWTH. 152.0. *Pinus taeda, P. echinata, P. clausa.*

OBJECT: To determine whether tip-moth injury during the early life of a plantation of susceptible species has an effect upon the final yield and quality of the stand.

METHODS: Paired, 81-tree plots of loblolly, shortleaf, and Choctawhatchee sand pine planted at a 7 x 9 spacing were established on cleared sandhill sites in 1960. Trees in one plot were chemically treated to prevent tip-moth damage.

COOPERATORS: Florida Board of Forestry; Hardaway Contracting Co.; Division of Forest Fire, Insects, and Disease Research.

ASSIGNMENT: Russell M. Burns, Research Forester.

25. UNITED STATES FOREST SERVICE, SOUTHEASTERN FOREST EXPERIMENT STATION

Olustee, Florida

25—1. ARBORETUM. 111.0. General.

OBJECT: To develop a combination breeding-introduction garden.

METHODS. Two plantations are being maintained, both on flatwoods soil but one on a wet site and the other on a drier site. Plots of *Pinus* consist of 25 tree squares spaced at 12 x 12. Both plantations are located on the Olustee Experimental Forest (Florida). The principal records being maintained are for seed source, plot establishment, growth rates, incidence of insect or disease damage, and phenology of flowering.

ASSIGNMENT: A. E. Squillace, Project Leader; C. R. Gansel, Associate Plant Geneticist.

25—2. COMPARISON OF FOUR PINE SPECIES ON A FLATWOOD SITE. 111.0. *Pinus* x *sondereggeri, P. palustris, P. taeda,* and *P. elliottii.*

OBJECT: To compare the relative growth of Sonderegger pine with that of longleaf, loblolly, and slash pines.

METHODS: In December 1953, 100 seedlings each of the four pines were planted in four replications on Leon fine sandy soil on the Olustee Experimental Forest in Florida. Spacing was 8 x 8.

ASSIGNMENT: Frank A. Bennett, Project Leader; Lawrence P. Wilhite, Associate Silviculturist.

25—3. SLASH PINE ECOTYPE STUDY. 111.1. *Pinus elliottii.*

OBJECT: This study attempts to answer the question whether slash pine has split into a wet site and a dry site type. The study is designed to test an abrupt change from wet to dry site rather than a gradual one.

METHODS: Seed were collected in 1952 from a stand on a pond margin and a stand on a dry site. Seedlings from both collections were planted in 1953 on a wet site in Union County, Florida, owned by the Owens-Illinois Glass Company and a dry site on the Olustee Experimental Forest (Florida). Each plantation consists of 4 randomized blocks containing two plots of 50 seedlings each. Spacing between rows is 8 feet and within the row 10 feet. Seedlings of both seed sources are also planted on wet and dry sites in the Corkscrew Experimental Forest in south Florida. The same design was used except that 5 blocks instead of 4 were planted. Early height measurements showed no distinct differences between trees from the two ecotypic sources.

COOPERATORS: Owens - Illinois Glass Company; Atlantic Land and Improvement Company.

ASSIGNMENT: A. E. Squillace, Project Leader; C. R. Gansel, Associate Plant Geneticist; J. E. Bethune, Associate Silviculturist.

25—4. SLASH PINE SEED SOURCE STUDY. 111.1. *Pinus elliottii.*

OBJECT: To prepare precise maps of slash pine seed collection zones for Florida and Georgia.

METHODS: Fourteen seed source collections were made in 1953. They covered the range of *Pinus elliottii* var. *elliottii* in Georgia and Florida. Outplantings of all seed sources were made in 1954 in Lake, Baker, and Liberty Counties (Florida), and Dooly and Effingham Counties (Georgia). Partial plantings were also made in Collier County, Florida, and Emanuel County, Georgia. Complete plantings consist of 4 blocks with the seed sources in randomized plots. Each plot contains 10 rows of 10 seedlings spaced at 8 x 8. Sources from the extreme south and extreme north of the slash pine range seem to be growing the slowest. Strong planting site effects have been noted.

COOPERATORS: Atlantic Land and Improvement Company; Owens-Illinois Glass Company; Continental Can Corporation; Union Bag-Camp Paper Corporation; U. S. Forest Service, Southern Forest Experiment Station; Florida National Forests.

ASSIGNMENT: A. E. Squillace, Project Leader; C. R. Gansel, Associate Plant Geneticist.

25—5. RACIAL VARIATION IN SLASH PINE. 111.1. *Pinus elliottii.*

OBJECT: To determine the patterns of geographic and racial variation in slash pine for various juvenile and mature tree characteristics and to search for possible correlations with environmental factors.

METHODS: In 1960 seed and foliar samples were collected from five randomly chosen trees at each of 54 collection points scattered throughout the natural range of both typical and South Florida slash pine. Seed were sown in the spring of 1961 and seedlings outplanted at four locations in 1962: Lake City, Florida; Fort Myers, Florida; Macon, Georgia; and Gulfport, Mississippi. Early results, including variation in seed and cone characteristics of the parents, foliar characters of both parents and progenies, and germination and early growth of progenies, are now being prepared for publication.

COOPERATORS: U. S. Forest Service, Institute of Forest Genetics at Gulfport; Southeastern Forest Experiment Station, of the U. S. Forest Service, at Macon, Ga., and Fort Myers, Fla.

ASSIGNMENT: A. E. Squillace, Project Leader; John F. Kraus, Plant Geneticist; E. Bayne Snyder, Plant Geneticist; and James W. McMinn, Associate Silviculturist.

25—6. PHYSIOLOGICAL RACES IN SLASH PINE. 111.1, 151.03. *Pinus elliottii.*

OBJECT: To determine whether; (1) seedlings from the geographic location where highest foliage-phosphorus concentrations were noted will make more rapid growth and/or accumulate more phosphorus than seedlings from outside this area when planted in phosphorus-poor flatwoods soil; (2) the nature and magnitude of the growth response to applied phosphate on flatwoods soil is uniform among various seed sources, and (3) foliage-phosphorus concentrations indicative of deficiency and sufficiency of phosphate in the soil vary with geographic seed source.

METHODS: The soil to be used is a poorly drained flatwoods type of Bladen-Weston series on which slash pine has responded strongly to phosphate fertilization. Slash pine seedlings of 1-0 nursery-grown stock from four sources within and six sources outside the zone of high foliage phosphate content will be tested with 0-, 5-, and 50-pounds per acre supplements of P supplied as concentrated (and highly soluble) superphosphate. Chemical analyses of the soil and seedling tissue will be made at the beginning of the experiment and 1 and 2 years after fertilizer treatment, to permit evaluation of treatment and seed source effects and their interaction on assimilation and nutrient accumulation by the trees.

COOPERATORS: Buckeye Cellulose Corporation; American Agricultural Chemical Company.

ASSIGNMENT: T. A. Harrington, Project Leader.

25—7. CLONAL ORCHARDS. 111.3. *Pinus elliottii.*

OBJECT: (1) To preserve the parent trees used in selecting and breeding slash pine; (2) to compare gum yields, growth rates, and form of the selected trees on the same site; and (3) to have a source of propagules for seed orchards.

METHODS: Three plantations are involved, all planted on flatwoods sites. They contain a total of 110 clones, each represented by from 1 to 15 ramets. The oldest of these plantations contains grafts made in January 1954. The youngest is still being added to.

COOPERATOR: Owens-Illinois Glass Company.

ASSIGNMENT: A. E. Squillace, Project Leader; C. R. Gansel, Associate Plant Geneticist.

25—8. SINGLE PARENT PROGENY TEST OF POOR FORM. 111.3, 13. *Pinus elliottii.*

OBJECT: To test progeny of 7 slash pine selected for their poor form.

METHODS: Progenies were grown from open-pollinated seed collected in 1952 and outplanted in 1953. The plantation is on a flatwoods site in the Olustee Experimental Forest (Florida) and consists of four blocks, each containing from 6 to 42 individual trees of each progeny planted as plots with the plots randomized within the blocks. Photographs of the parents are on file and comparisons of the progeny with the parents will be made when the progeny are large enough.

ASSIGNMENT: A. E. Squillace, Project Leader; C. R. Gansel, Associate Plant Geneticist.

25—9. OUTPLANTING OF ROOTED CUTTINGS OF HIGH GUM-YIELDING PHENOTYPES. 111.3, 141. *Pinus elliottii.*

OBJECT: (1) To preserve the parent trees used in selecting and breeding high gum-yielding slash pine; (2) to compare gum yields of the selected trees on the same site; and (3) to have a source of propagules for seed orchards.

METHODS: The plantation is located on a flatwoods site in the Olustee Experimental Forest (Florida) and contains from 1 to 8 ramets of 16 selected trees. Most of the cuttings were outplanted in 1943. Trees were used with those in other studies to demonstrate the inheritance of several traits. Male and female flowers are being used in controlled crosses with new selections.

ASSIGNMENT: A. E. Squillace, Project Leader; C. R. Gansel, Associate Plant Geneticist.

25—10. NURSERY SELECTION FOR SUPERIOR HEIGHT GROWTH. 111.3. *Pinus elliottii.*

OBJECT: To establish a plantation of outstanding slash pine seedlings to be used for future breeding work and as a possible future seed supply source.

METHODS: The plantation was established in 1953 on a flatwoods site in Union County, Florida, owned by the Owens-Illinois Glass Company. It consists of 1,060 superior seedlings selected from the Olustee State Nursery planted in rows of 25 seedlings each. Four alternate rows in the center of the plantation are planted with average seedlings as a check. Spacing between rows, and trees in the row, is 12 feet. Eighth-year measurements showed the selected trees had an average height superiority of 23 percent over controls. Survival of the select seedlings was 35 percent versus 66 percent for controls. None of the select trees was superior to the best of the controls.

COOPERATOR: Owens-Illinois Glass Company.

ASSIGNMENT: A. E. Squillace, Project Leader; C. R. Gansel, Associate Plant Geneticist.

25—11. INHERITANCE OF SPECIFIC GRAVITY IN SLASH PINE. 111.3, 112.02, 141, 151.321. *Pinus elliottii.*

OBJECT. To obtain information on the variation and inheritance of specific gravity in slash pine.

METHODS: 10-mm. increment cores were taken from 4 groups of trees as follows: 500 progenies, 14 years old, wind and controlled pollinated; 47 rooted cuttings, 14 years old, from seven clones; 47 trees, 25 years old, in a plantation; and 25 trees, varying from 20 to 40 years in age and located in natural stands in north-central Florida and south-central Georgia. Specific gravity and summerwood percent were determined. Narrow-sense heritability estimated from the progeny data was 21 percent for wind pollinations and 56 percent for control pollinations. Summerwood percent heritabilities were about one-half as large as for specific gravity. Specific gravity was also found to be inversely related to d.b.h. and directly related to total height, to a moderately strong degree, in the older groups of trees.

COOPERATOR: U. S. Forest Service, Institute of Forest Genetics at Gulfport.

ASSIGNMENT: A. E. Squillace, Project Leader; C. R. Gansel, Associate Plant Geneticist.

25—12. BREEDING AND PROGENY TESTING FOR SELECTION OF HIGH GUM-YIELDING GENOTYPES OF SLASH PINE. 112.02. *Pinus elliottii.*

OBJECT: To obtain for future seed orchard establishment at least 12 more proven superior gum-yielding genotypes of slash pine.

METHODS: Selected superior phenotypes are being control bred with three already proven genotypes. The seed produced will be outplanted in progeny testing plantations. Work will continue until the desired new proven genotypes have been obtained. Fifteen progenies were outplanted in 1962 in 2-tree plots replicated 10 times.

ASSIGNMENT: A. E. Squillace, Project Leader; C. R. Gansel, Associate Plant Geneticist.

25—13. POLYCROSSING AND PROGENY TESTS OF SELECTED SLASH PINES. 112.02. *Pinus elliottii.*

OBJECT: (1) To produce a population of trees which will possess superiority in two or more desired characteristics to be used for further selection and breeding, and (2) to progeny test available selected phenotypes.

METHODS: (1) Controlled pollination of selected trees for 3 years using a mixture of pollens from genotypes and phenotypes selected for high oleoresin yield, high wood specific gravity, and fast growth; (2) progeny testing of selections through use of wind-pollinated seed; (3) progeny testing through use of control-pollinated seed produced in (1). Forty-five progenies were planted in 1961 in row plots of 4 trees each, replicated 10 times.

COOPERATORS: I. J. Langdale; Southern Resin and Chemical Company; Union Bag-Camp Paper Corp.; Georgia Coastal Plain Experiment Station; Mrs. Elizabeth Davis; Florida National Forests; Florida Forest Service; State Armory Board.

ASSIGNMENT: A. E. Squillace, Project Leader; C. R. Gansel, Associate Plant Geneticist.

25—14. PROGENY TEST OF HIGH GUM YIELDERS. 112.02, 112.03, 141. *Pinus elliottii.*

OBJECT: (1) to test the progeny from controlled crosses between four high gum-yielding slash pine, and (2) to determine which of these are high gum-yielding genotypes.

METHODS: Controlled breeding was done in 1947 and 1948. Progenies were outplanted in 1951. The plantation is located on a flatwoods site in the Olustee Experimental Forest (Florida) and consists of four blocks each containing 11 crosses including trees rated as high x high, high x self, high x wind, and average x wind. The crosses are arranged in plots varying in size from 2 to 18 trees. The plots are randomly situated within the blocks. Three extra blocks contain crosses represented by a few individuals. The depression of growth rate by selfing has been shown in this plantation. The trees were microchipped in 1961. The results substantiated those found in other studies, but no new high-yielding genotypes were found.

ASSIGNMENT: A. E. Squillace, Project Leader; C. R. Gansel, Associate Plant Geneticist.

25—15. PROGENY TEST OF HIGH GUM-YIELDERS. 112.02,141. *Pinus elliottii.*

OBJECT: To test the progeny from controlled crosses between six high gum-yielding slash pine and to determine which of these are high gum-yielding genotypes.

METHODS: Controlled breeding was done in 1943 and 1944. Progenies were outplanted in 1945. The plantation is located on a typical flatwoods site in the Olustee Experimental Forest (Florida) and consists of 7 blocks each containing 14 crosses including trees rated as high x high, high x wind, average x average, and average x wind. Each cross is represented by two to five individual trees in each block. Three extra blocks contain crosses represented by a few individuals. Microchipping in 1954 and in 1956 indicates that three trees are high-yielding genotypes. Inheritance of gum viscosity, gum exudation pressure, stem crook, tracheid length, bark thickness, specific gravity, summerwood percent, crown width, d.b.h., height, volume, needle length, needle bundle volume, fascicle sheath length, needle divergence, and bud scale length have also been shown in this plantation.

ASSIGNMENT: A. E. Squillace, Project Leader; C. R. Gansel, Associate Plant Geneticist.

25—16. SELECTION, BREEDING, AND PROGENY TESTING OF F_1 TREES IN PLANTATION 0-116. 112.02, 141. *Pinus elliottii.*

OBJECT: To evaluate the best nine F_1 phenotypes in a progeny test plantation for inherent high gum yield.

METHOD: These nine clones are currently being used in seed orchards. Crosses made included full-sibs, half-sibs, backcrosses, and selfs. The seed produced were outplanted in a progeny testing plantation in 1962. Eighteen progenies were planted in 2-tree plots replicated 10 times.

ASSIGNMENT: A. E. Squillace, Project Leader; C. R. Gansel, Associate Plant Geneticist.

25—17. HIGH GUM-YIELD SEED PRODUCTION AREA. 122.0, 13. *Pinus elliottii.*

OBJECT: To determine the feasibility of establishing a seed-production area to produce seed having moderately superior gum-yielding ability, growth rate, and timber quality.

METHODS: The area covers 10 acres in a 19-year-old plantation on the Osceola National Forest in Florida. Original spacing was about 8 x 8 feet and there are 400 to 500 trees per acre. About 200 trees per acre are to be microchipped to indicate gum-yield capacity. After chipping, the final selection of trees to be left in the seed-production area will be made. Twenty-five trees per acre will be left, on a basis of good gum yield, volume growth, and tree form.

ASSIGNMENT: A. E. Squillace, Project Leader.

25—18. SEED ORCHARD FOR HIGH GUM YIELDERS. 122.1. *Pinus elliottii.*

OBJECT: Intended as an experimental planting to facilitate study of seed orchard management, the study will also furnish slash pine seed of high quality for gum production.

METHODS: Planting is on a 5-acre area of the Osceola National Forest. Irrigation is being provided as needed through ditches between the rows. Clonal material is being supplied by nine of the best trees in a progeny testing plantation with most of the propagation by airlayering. Spacing between rows and trees is 30 x 30.

COOPERATOR: Florida National Forests.

ASSIGNMENT: A. E. Squillace, Project Leader; C. R. Gansel, Associate Plant Geneticist.

25—19. INTENSIVE PLANTATION MANAGEMENT. 13. *Pinus elliottii.*

OBJECT: (1) To develop optimum rotations for slash pine plantations of varying site indices and stand densities and with varying market values for pulpwood and naval stores, and (2) to determine the optimum planting density in slash pine plantations managed for joint production of pulpwood and naval stores.

METHODS: The study will be divided in two phases: (1) development of the necessary mensurational information, and (2) the develment of optimum management techniques. Much data already in the files will be used in conducting the study.

COOPERATOR: University of Georgia.

ASSIGNMENT: Frank A. Bennett, Project Leader; Jerome L. Clutter, Professor.

25—20. THE INHERITANCE OF SEED AND SEED-WING CHARACTERS IN SLASH PINE. 141. *Pinus elliottii.*

OBJECT: (1) To measure the parent-progeny relationships of seed and seed-wing characters of a selected population of slash pine, and (2) to determine if possible the mode of inheritance of one or more of the characters studied.

METHODS: Cones were collected from trees in test plantings made in 1957, 1961, and 1962. Measurements are being made of seed shape, seed coat thickness, seed color, seed weight, wing shape, and wing color. Heritabilities will be estimated from variance components and parent progeny relationships determined by regression and correlation.

ASSIGNMENT: John F. Kraus, Plant Geneticist.

25—21. EXPLORATION OF MICROCHIPPING AT JUVENILE AGE TO EVALUATE GUM-YIELDING POTENTIAL IN SLASH PINE. 151.0. *Pinus elliottii.*

OBJECT: To explore a technique for determining the gum-yielding potential of trees at a very early age.

METHODS: Progenies of proven high- and low-oleoresin-yielding trees plus suitable controls were grown at wide spacing (18 inches x 18 inches) in the nursery for 2 years. The resulting saplings were microchipped during the late summer of their second year in the nursery.

ASSIGNMENT: A. E. Squillace, Project Leader.

25—22. TOPOPHYSIS AS RELATED TO GROWTH AND FORM OF SLASH PINE AIRLAYERS. 151.0. *Pinus elliottii.*

OBJECT: (1) To determine whether topophysis exists in slash pine and if so the extremes in variation in growth or form which can be expected; (2) to determine the relative root-ability of branches from the extremes of the crown and of first order and second order branches; and (3) to establish possible leads as to the physiological factors controlling growth rate and growth habit in slash pine.

METHODS: Airlayers were installed on terminal, first-order, and second-order branches in the upper and lower crown of four open-grown, 25-year-old slash pine in August 1960. The rooted airlayers available in June 1961 were planted in two blocks of eight airlayers each. Height will be measured annually for 5 years and observations made on stem development.

ASSIGNMENT: T. A. Harrington, Project Leader.

25—23. STIMULATION OF FLOWERING. 151.01. *Pinus palustris.*

OBJECT: To determine effects of branch girdling on female flowering in longleaf pine.

METHODS: Five pairs of primary branches on each of 15 trees will be used and one branch of each pair will be girdled. Branch elongation will be observed as well as flower production.

ASSIGNMENT: Frank A. Bennett, Project Leader.

25—24. STIMULATION OF FLOWERING. 151.01. *Pinus elliottii.*

OBJECT: To determine feasibility of increasing female flowering in slash pine by girdling branches.

METHODS: Seven, open-grown, well-formed, cone-bearing trees about 15 years old are being used. Ten large, first-order branches were selected in the upper portion of the crown of each tree. Five branches were girdled and five left as checks. The study was designed for analysis as a randomized complete-block experiment.

ASSIGNMENT: Frank A. Bennett, Project Leader; Ray J. Varnell, Associate Silviculturist.

25—25. AIRLAYER AND GRAFT GROWTH RESPONSE AND SUCCESS BY TREE AGE. 151.02. *Pinus elliottii.*

OBJECT: (1) To determine the differential growth response of slash pine airlayers and graft scions taken from 5-, 10-, 20-, and 40-year-old trees, and (2) to compare the growth of airlayers from 10-year-old trees and 10-year-old cuttings that originally came from 30-year-old trees.

METHODS: The outplanting was completed in 1958 on a flatwoods site in the Olustee Experimental Forest, and consists of five replicated blocks each containing two propagules from each of the five age classes and for each propagation method, a total of 20 trees per block. Spacing is 12 x 12 feet.

ASSIGNMENT: A. E. Squillace, Project Leader; C. R. Gansel, Associate Plant Geneticist.

25—26. SURVIVAL AND GROWTH OF PINES ON VARIOUS SITES. 151.09. *Pinus elliottii, P. palustris, P. taeda,* and *P. clausa.*

OBJECT: To compare the survival and growth of planted pines on four soil types on the lower Coastal Plains.

METHODS: In January 1958, 64 seedlings each of longleaf, loblolly, slash, and sand pine were planted in two replications on Blanton fine sand, Leon fine sand (hardpan phase), Leon fine sand (softpan phase), and Plummer fine sand on the Olustee Experimental Forest in Florida. For the survival phase of the study, two seedlings were planted 12 inches apart at each spot and plantation spacing was 6 x 8.

ASSIGNMENT: Frank A. Bennett, Project Leader; Lawrence P. Wilhite, Associate Silviculturist.

25—27. STUDIES OF THE IDENTIFICATION, BIOLOGY, ECOLOGY, AND CONTROL OF INSECTS AFFECTING THE SEED PRODUCTION OF SLASH AND LONGLEAF PINES. 152.0. *Pinus elliottii, P. palustris.*

OBJECT: (1) To identify the major insects destructive to flowers, cones, and seeds; (2) to study the life histories, behavior, and ecological insect-host tree relationships of the important insects; and (3) to develop chemical and biological methods for the control of economically destructive cone and seed insects.

METHODS: This project initiated in 1957 embraces many laboratory and field studies, the ultimate goals of which are to develop economically and entomologically sound methods for controlling insects affecting seed production in seed orchards, natural seed production stands, and high-value tree improvement plantings.

ASSIGNMENT: C. W. Fatzinger and E. P. Merkel, Research Entomologists.

25—28. PRUNING OF SLASH PINE SEED ORCHARDS. 154.3. *Pinus elliottii.*

OBJECT: To develop a seed orchard pruning technique which will produce the maximum cone producing crown area while limiting the tree to a manageable height.

METHODS: Established in 1957 in a plantation on a flatwoods site. The study tests four pruning treatments on trees in three height classes, treatments to begin as the trees attain their assigned height. Records are kept of time spent pruning, time consumed in cone collection, and number of cones produced. Field layout consists of four blocks, each containing 12 trees. Spacing is approximately 32 x 32. Cultural treatments include cultivation, fertilization, and protection from severe insect and disease damage.

COOPERATOR: Owens-Illinois Glass Company.

ASSIGNMENT: A. E. Squillace, Project Leader; C. R. Gansel, Associate Plant Geneticist.

26. UNITED STATES FOREST SERVICE, SOUTHERN FOREST EXPERIMENT STATION

Alexandria, Louisiana

26—1. SPECIES-SITE ADAPTATIONS. 111.0. *Pinus elliottii, P. palustris, P. taeda, P. echinata.*

OBJECT: To determine the different sites in south Mississippi and Louisiana and to determine which is the correct species for each of these sites. While this study was not designed as a tree improvement study, a knowledge of the forest sites is necessary in properly evaluating genetic material.

METHODS: One - hundred - twenty plots were established over a 4-year period (1954-1957) throughout south Mississippi and Louisiana. Each plot contained longleaf, slash, and loblolly pine planted in square subplots of 121 or 144 seedlings each at 6 x 6 spacing. These subplots were arranged in a randomized complete block design with three replications. About one-third of the plots contained shortleaf subplots. Growth measurements of the trees are being made at 5-year intervals. Soils analyses are being made on the plots.

COOPERATOR: L. N. Dantzler Lumber Company; Gaylord Container Corporation; Division of Crown-Zellerbach Corporation; International Paper Company; University of Mississippi, University Lands; Mississippi Forestry Commission; U. S. Forest Service, Mississippi National Forest; U. S. Forest Service, Kisatchie National Forest; Bodcaw Company; Continental Can Corporation; A. J. and Nona Trigg Hodges Gardens, Inc.; Tremont Lumber Company; Olin Mathieson Chemical Corporation; Lutcher-Moore Lumber Company; T. C. James and Company; Edgewood Land and Logging Company; Urania Lumber Company; Rice Land and Logging Company; Union Producing Company; Humble Oil Company; Hillyer Duetsch Edwards, Inc.

ASSIGNMENT: Eugene Shoulders, Research Forester.

26—2. GEOGRAPHIC SOURCES OF LONGLEAF, SLASH, LOBLOLLY, AND SHORTLEAF PINE SEEDS, 1935 CROP. 111.1. *Pinus taeda, P. palustris, P. echinata, P. elliottii.*

OBJECT: To study (geographic) racial variation of four major southern pines.

METHODS: The study was established in 1936-37 (with a few follow-up plots a year later) by planting 11 geographic sources of longleaf pine, 7 of slash pine, 12 of loblolly pine, and 13 of shortleaf pine, each species in 3 balanced, randomized-block replications (less a few missing plots because of shortages of stock) in square plots, 400 trees per plot, at 6 x 6-foot spacing; total area, approximately 56 acres. This was the largest installation of a regionwide study that failed because of establishment deficiencies and other mishaps. Inroads of fire and hogs during World War II have precluded any meaningful measurements of survival and growth to date, except for a wood-specific-gravity determination of the slash pine component by Echols, a comparison of basal area, merchantable volume, and fusiform rust infection in the slash pine at age 22 by Derr and Enghardt, and a study of gum yield in the slash pine by Barrett. The plantations are, however, an invaluable source of racial breeding material, and the Crossett Research Center has made and outplanted (at Crossett, Arkansas) about 10 interracial crosses with pollen from the loblolly component. The plantations at Alexandria are being preserved for future observation and breeding. Study is located at Alexandria, Rapides Parish, Louisiana (J. K. Johnson Tract), on upper coastal plain site. Surplus seed was donated to the Union of South Africa and results were published by S. P. Sherry in 1947.

COOPERATOR: Institute of Forest Genetics at Gulfport.

ASSIGNMENT: William F. Mann, Jr., Project Leader.

26—3. HYBRIDIZATION OF SOUTHERN PINES. 112.01. *Pinus elliottii, P. palustris, P. echinata.*

OBJECT: To explore (1) the crossability of southern pine species, and (2) the possibility of mass-producing *Pinus palustris* × *P. elliottii* without bagging.

METHODS: *P. echinata* × *P. elliottii* was made under control in 1951; *P. palustris* × *P. elliottii* has been made extensively since, including some by method (2) above. Progenies are outplanted, largely arboretum-style but with some provision for t tests, at Millard, Mississippi, on the Crossett Experiment Forest, Crossett, Arkansas, and on the Palustris Experimental Forest. Some data are also available on natural crosses of *P.* × *sondereggeri* × *P.* × *sondereggeri, P.* × *sondereggeri* × *P. palustris,* and *P.* × *sondereggeri* × *P. taeda* from a 7-acre Sonderegger pine plantation on the Kisatchie National Forest and from isolated Sonderegger pines on the Palustris Experimental Forest. Crosses were made at Alexandria, Rapides Parish, Louisiana, on and near the J. K. Johnson Tract, on upper coastal plain sites.

COOPERATORS: Crossett Research Center; Southern Timber Operations, Crown-Zellerbach Corp.; Louisiana Forestry Commission.

ASSIGNMENT: Harold J. Derr, Hoy C. Grigsby, Research Foresters.

26—4. HYBRIDIZATION OF SOUTHERN PINES. 112.01. *Pinus palustris, P. elliottii.*

OBJECT: To study the growth rate and disease resistance of longleaf × slash hybrids. Emphasis will be on brown-spot resistance of this hybrid, although its susceptibility to fusiform rust will also be evaluated.

METHODS: Since 1954, approximately 3,000 hybrid seedlings have been produced on 20-25 female parent trees using pollen from local planted stands. Outplantings on both the Johnson Tract and the Longleaf Tract of the Palustris Experimental Forest include wind-pollinated half-sibs and slash pines obtained from State nurseries. Most outplantings are randomized block (3 to 4 replications) with either a 20- or 25-tree row serving as a treatment plot. Spacings are either 6 x 8 or 8 x 8. All crosses have been made on or near the Johnson Tract, Palustris Experimental Forest, in Rapides Parish, Louisiana, on upper coastal plain sites.

COOPERATOR: U. S. Forest Service, Institute of Forest Genetics at Gulfport.

ASSIGNMENT: Harold J. Derr, Research Forester.

26—5. HYBRIDIZATION OF SOUTHERN PINES. 112.01. *Pinus* spp.

OBJECT: To explore (1) the crossability of southern pine species and the performance of 2-, 3-, and 4-species hybrids, F_2 progenies of Sonderegger pine and back-crosses of this hybrid to both its parents, the performance of progenies of members of a longleaf-loblolly hybrid swarm, and the results of selfing, and (2) the possibility of mass-producing longleaf x slash and shortleaf x slash hybrids without bagging.

METHODS: Beginning in 1954, proved or putative hybrids have been produced on upwards of 100 female parent trees of longleaf (predominating), Sonderegger, loblolly, shortleaf, and slash pines, using pollen from local and Mississippi sources and from the Eddy Arboretum at Placerville, California. Arboretum-type, t test, and pilot-plant outplantings, including supplementary outplantings on the Crossett and Harrison Experimental Forests, total several acres. Majority of crosses and main outplantings on A. J. Hodges Experimental Area, Many, Sabine Parish, Louisiana; some supplementary crosses at DeRidder, Beauregard Parish, Louisiana; all on upper coastal plain sites.

COOPERATORS: Crossett Research Center; Institute of Forest Genetics at Gulfport; Long Bell Lumber Company.

ASSIGNMENT: Hoy C. Grigsby, Research Forester.

26—6. INHERITANCE OF INDIVIDUAL-TREE CHARACTERS. 141. *Pinus palustris.*

OBJECT: To study the inheritance of (1) black seed coat, and (2) brown-spot resistance in longleaf pine.

METHODS: Beginning about 1953, collections of wind-pollinated cones have been made from, and a variety of controlled pollinations have been made on, three longleaf pines having the rare character "black-seed," and on one longleaf pine nursery-selected about 1937 and having unusual resistance to brown-spot ("Father Abraham, the mother of a new race!"), and suitable check trees. Outplantings of resulting progenies have been made at various places in Louisiana and Mississippi. The collections and controlled crosses have been made in Rapides and Grant Parishes, near Alexandria, Louisiana, on upper coastal plain sites.

COOPERATORS: A. J. Hodges Forest Products Co., Inc.; U. S. Forest Service, Institute of Forest Genetics at Gulfport.

ASSIGNMENT: Harold J. Derr, Research Forester.

26—7. SOUTHERN PINE POLLINATION TECHNIQUES. 154.0. *Pinus palustris, P. elliottii, P. taeda.*

OBJECT: To improve the reliability and efficiency, and to clarify some of the basic relationships, of controlled pollination of the southern pines, particularly longleaf.

METHODS: Work mostly on longleaf pine female parents, with longleaf, slash, and loblolly pine pollens. Preliminary work in 1954 on pollen extraction, on bagging techniques, on pollinizers, and on mass pollination (hybridization) without bagging. Beginning in 1958, rigorously designed studies of stages at which to bag and to pollinate, of duration of flower receptivity, of competitive ability of pollen of alien species, and of diagnostic value of laboratory germination tests of fresh and stored pollen. Designs typically multifactorial, with two or three trees either as blocks or as treatments, depending on superimposed pollen or pollination-treatment combinations; 12 to 36 or more observations per experiment, each consisting of five to ten bags per treatment-combination per tree. Results in terms of cones maturing, seeds filled, and, in some phases, hybrid seedlings produced. Controlled pollinations on A. J. Hodges Experimental Area, Many, Sabine Parish, Louisiana, on upper coastal plain sites.

COOPERATOR: U. S. Forest Service, Institute of Forest Genetics at Gulfport.

ASSIGNMENT: E. B. Snyder, Research Forester.

27. UNITED STATES FOREST SERVICE, SOUTHERN FOREST EXPERIMENT STATION

Crossett, Arkansas

27—1. EXOTIC TRIALS IN SOUTHWESTERN ARKANSAS. 111.0, General.

OBJECT: To discover exotic species, varieties, strains, or hybrids which will thrive in this area and which have traits that make them desirable for forestry purposes. They will also be used in the breeding and hybridization program to combine certain desirable characters with those of native species.

METHODS: Various species of trees not native to the south Arkansas-north Louisiana area were planted over a period of 5 years beginning in the spring of 1954. These plantings are made on 18 plots in five test areas. Two demonstration plots were planted in 1955 involving 25 and 26 species each. Five seedlings were planted per row with rows being replicated from two to five times where the seedlings were available. In 1956, twelve additional plantations were made on various site conditions. The number of species varied from 12 to 25 at each site. Each species was planted in plots of 25 at a spacing of 8 x 8. A total of 29 coniferous species (including two native species) was planted. In 1957, another plantation involving 50 species was planted with 8 by 8 foot spacing. Plantations are on Ozan Lumber Company land, Nevada, Hempstead, Clark, and Pike Counties, Arkansas, and the Crossett Experimental Forest, Ashley County, Arkansas.

COOPERATOR: Ozan Lumber Company.

ASSIGNMENT: Hoy C. Grigsby, Associate Plant Geneticist.

27—2. A PERFORMANCE AND PROGENY TEST FOR SEVEN PINE SEED LOTS FROM ARKANSAS, LOUISIANA, AND MISSISSIPPI. 111.0, 111.1. *Pinus taeda, P.* × *sondereggeri, P. glabra,* and *P. echinata.*

OBJECT: To compare further the performance of two sources of Mississippi loblolly pine with loblolly from southeastern Arkansas; to test the progeny of a Mississippi loblolly pine plus tree candidate and a Louisiana Sonderegger hybrid backcross, to compare the growth of spruce pine and shortleaf pine with the above sources, and to compare informally the survival and growth of the seedlings on these plots with the seedlings on the adjacent direct seeding plots of another study.

METHODS: Seedlings from the seven sources were planted 8 by 8 feet on tenth-acre plots and replicated three times. The plantation is on Bradley-Southern Division land, Bradley County, Arkansas.

COOPERATOR: Bradley-Southern Division of Potlatch Forests, Inc.

ASSIGNMENT: Hoy C. Grigsby, Associate Plant Geneticist.

27—3. A TEST OF 36 GEOGRAPHIC SOURCES OF LOBLOLLY PINE SEED IN SOUTHERN ARKANSAS. 111.1. *Pinus taeda.*

OBJECT: To determine what sources, if any, will grow as well or possibly better than the native loblolly on its own site so that the information can be used to determine the areas from which seed can be secured in case of failure in the local seed crop. Also, to obtain information in regard to wood quality and density and resistance to disease and insects.

METHODS: The experiment is set up on the same design and work plan as the Southwide pine seed source study sponsored by the Committee on Southern Forest Tree Improvement and involves a total of 35.5 acres. All seed sources are replicated from 4 to 12 times. This test involves 36 sources of loblolly pine from 13 states or throughout its natural range from Maryland to Texas. Plantings are on Ozan Lumber Company land, Hempstead County, Arkansas, and Georgia-Pacific Corp. land, Cleveland County, Arkansas.

COOPERATORS: Ozan Lumber Company; Georgia-Pacific Corporation.

ASSIGNMENT: Hoy C. Grigsby, Associate Plant Geneticist.

27—4. LOCAL TEST OF CROSSETT PINE SEED. 111.1. *Pinus taeda.*

OBJECT: To test the performance of Crossett seedlings with stock from other seed sources in the South in their local environment: (1) to determine if Crossett seed and seedling stock are equal to—or possibly superior to—local seed within carefully defined areas, and (2) to locate seed source provenances which are as satisfactory as—or possibly better than—that of Crossett for planting in the Crossett area.

METHODS: Cooperators consisting principally of industries, public forestry agencies, and schools have installed a total of 19 successful plantations involving 88 seed sources on 35 acres of land in nine southern states. Series I plots were established in 1954, Series II in 1955, and Series III in 1956. The plantings were made in randomized block design according to the "Standardized Working Plan for Local Tests of Seed Source" prepared by the Committee on Southern Forest Tree Improvement, Subcommittee on Geographic Source of Seed, under the direction of Philip C. Wakeley. Plantations are located in Bienville, Rapides, Washington, and Lincoln Parishes, Louisiana; Pike and Tishomingo Counties, Mississippi; Anderson and Franklin Counties, Tennessee; Ashley and Hempstead Counties, Arkansas; Shelby County, Texas; Lauderdale and Autauga Counties, Alabama; Columbia County, Florida; and Georgetown County, South Carolina.

COOPERATORS: Continental Can Company; Louisiana Forestry Commission; School of Forestry, Louisiana State University; Mississippi Forestry Commission; Tennessee Valley Authority; Georgia-Pacific Corp.; University of Arkansas; S. C. Kardell; Department of Forestry, Louisiana Polytechnic Institute; School of Forestry, Auburn University; Florida Ranger School, University of Florida; West Virginia Pulp and Paper Company.

ASSIGNMENT: Hoy C. Grigsby, Associate Plant Geneticist.

27—5. MORPHOLOGICAL SEEDLING TYPES AS POSSIBLE INDICATORS OF GENOTYPES IN LOBLOLLY PINE. 111.3. *Pinus taeda.*

OBJECT: This study tests the possibility that different morphological loblolly pine seedling types in nursery beds can result in trees with distinctive genetic traits.

METHODS: Six distinctive seedling types were selected and planted in randomized row design in four blocks: (Type 1) Seedlings with a terminal bud. No side branches. Secondary needles of normal length. (Type 2) Seedlings with a terminal bud and at least one whorl of side branches. Secondary needles normal length. (Type 3) Seedlings with terminal bud and no side branches. Secondary needles very long. (Type 4) Seedlings with no terminal bud. Have candle present. No side branches. Secondary needles normal length. (Type 5) Seedlings with no terminal bud. Candles recently opened to reveal primary needles. No side branches. Secondary needles normal. (Type 6) Seedlings with no terminal bud and no side branches. All needles primary. This plantation was established in 1958. It contains 21 trees of each of the six types replicated four times. Plantations are in the Crossett Experimental Forest on loess over coastal plain soil.

ASSIGNMENT: Hoy C. Grigsby, Associate Plant Geneticist.

27—6. PLUS TREE SELECTION PROGRAM. 111.3. *Pinus echinata, Pinus taeda.*

OBJECT: To set up specifications for the selection of superior tree phenotypes and to list the superior trees selected to date giving the traits of the individual trees in detail.

METHODS: One hundred ten carefully selected trees are included in the program at present. The number varies. Some trees are being dropped as testing progresses and others added as better trees are found. The normal procedure in testing these superior tree candidates is: (1) collect cuttings for vegetative propagation (rooting or grafting) as soon as possible, (2) collect open-pollinated cones for one-parent progeny test the first cone harvest, and (3) control-breed the tree to other trees with desirable traits for testing the heritability of traits from both parents. Offspring produced by one or more of these methods have been obtained from most of these 110 trees and are now growing in test areas. The study is located in southeast Arkansas on loess over coastal plain soil.

COOPERATOR: Georgia-Pacific Corp.

ASSIGNMENT: Hoy C. Grigsby, Associate Plant Geneticist.

27—7. PHENOTYPIC VARIATION IN THE PROGENY OF OPEN-POLLINATED, SELECTED LOBLOLLY PINE PARENT TREES. 111.3. *Pinus taeda.*

OBJECT: To determine the variation existing among the progeny of an open-pollinated parent and general differences between the performance of progeny from one parent to another.

METHODS: Seed was collected from 16 parent trees with special characteristics such as large crowns, black seed, or large cones. The seedling stock was planted in 4 blocks of 15 randomized rows of 10 seedlings each. Insufficient seedlings did not allow four replications of all sources. The outplantings were made in 1955 on the Crossett Experimental Forest area on loess over coastal plain soil.

COOPERATOR: Georgia-Pacific Corp.

ASSIGNMENT: Hoy C. Grigsby, Associate Plant Geneticist.

27—8. AN OPEN-POLLINATED PROGENY TEST OF SEED COLLECTED FROM BULL PINES. 111.3. *Pinus taeda.*

OBJECT: To determine whether the undesirable features of the bull pine are controlled by heredity or whether they are due entirely to environment.

METHODS: The progeny of eight heavily limbed, poorly pruned bull loblolly pine trees were planted in six blocks in randomized paired row design with bed-run nursery seedlings. Ten seedlings were planted per row. The outplantings were made in 1957 on Ozan Lumber Company land, Hempstead County, Arkansas.

COOPERATOR: Ozan Lumber Company.

ASSIGNMENT: Hoy C. Grigsby, Associate Plant Geneticist.

27—9. THE SELECTION OF SUPER SEEDLINGS FROM NURSERY BEDS. 111.3. *Pinus taeda, P. echinata.*

OBJECT: To determine whether the super seedlings found in nursery beds will develop into super trees.

METHODS: Selections were made on the basis of height. A seedling of average height and one considered to be a runt were selected from the immediate vicinity of each super seedling and planted along with it in the test plots as checks. These seedlings were planted adjacent to one another in randomized rows and blocks, each size class falling in a separate row. Plantings were made in 1954, 1955, and 1956. A total of 166 plots has been planted in 23 plantations. All of these plantations involve 8.8 acres in south Arkansas and north Louisiana Coastal Plain.

COOPERATORS: Georgia-Pacific Corp.; Ozan Lumber Company; Louisiana Polytechnic Institute; Continental Can Company; Union Producing Company; Deltic Farm and Timber Company.

ASSIGNMENT: Hoy C. Grigsby, Associate Plant Geneticist.

27—10. EFFECT OF INTENSITY OF SELECTION ON LOBLOLLY PINE IMPROVEMENT. 111.3. *Pinus taeda.*

OBJECT: To test the degree of genetic improvement obtainable from the progeny of wind-pollinated pole and piling quality trees compared to that obtained from the progeny of wind- and control-pollinated plus trees.

METHODS: Seed from 13 loblolly pine geographic sources are replicated four times in randomized plots of 121 trees each. Test includes progenies from ten wind-pollinated plus tree selections, a controlled cross of two of these, a mix from pole and piling quality trees, and a mix from unselected trees for a control.

COOPERATOR: Georgia-Pacific Corp.

ASSIGNMENT: Hoy C. Grigsby, Associate Plant Geneticist.

27—11. FIRST HYBRID PINE PLANTATIONS AT CROSSETT. 112.01, 112.02. *Pinus* spp.

OBJECT: (1) To obtain information on relative growth and form of the various hybrids of the major southern pines and their varieties; (2) to supply pollen and cuttings; and (3) to provide parent trees for breeding work.

METHODS: Plantation 1 was established in 1954, and consisted of 19 hybrid lots from control-pollinations made at the Alexandria Branch Station and at the Harrison Experimental Forest in 1951. Seedlings from one natural hybrid were also used. The seedlings are all in one plot. The original planting was in randomized rows of five trees each. Much inter-planting altered this design somewhat. Plantations 2 and 3, established in 1956, consist of 19 hybrid and control lots derived chiefly from crosses made at the Crossett Branch in 1953, and at Placerville, California, in 1952. These seedlings are contained in two plots and are planted in randomized rows, 10 trees per row. Each row is replicated two to three times. Plantations are in the Crossett Experimental Forest, Ashley County, Arkansas on loess over coastal plain soil. Hybrids planted were: *Pinus elliottii elliottii* x *P. echinata* and reciprocal, *P. echinata* x *P. taeda, P. elliottii elliottii* x *P. elliottii densa, P. taeda* x *P. elliottii densa,* and *P. taeda* x *P. palustris.*

ASSIGNMENT: Hoy C. Grigsby, Associate Plant Geneticist.

27—12. THE TREATMENT OF PINE SEED WITH ULTRASONICS TO INDUCE POSSIBLE CYTOGENETIC EFFECTS. 112.11. *Pinus taeda.*

OBJECT: To produce chromosomal aberrations and mutations.

METHODS: The ultrasonic (sound radiation above the normal audible limit) treatments were made at a frequency of 400 kilocycles and at an intensity of 200 watts. Four seed lots were immersed in water (which served as a carrier for the sound waves) and treated with the ultra-sonorator for periods of 2, 4, 8, and 16 minutes, respectively. The resultant seedlings were planted in 1955 in four blocks. Each block contained eight plots, four from treated and four from untreated seed. Each plot contained 49 seedlings and all are in the Crossett Experimental Forest, on loess over coastal plain soil.

COOPERATORS: Georgia-Pacific Corp.; Agricultural Research Center, Beltsville, Maryland.

ASSIGNMENT: Hoy C. Grigsby, Associate Plant Geneticist.

27—13. THE USE OF GAMMA IRRADIATION TREATMENTS ON LOBLOLLY PINE SEED TO INDUCE POSSIBLE CYTOGENETIC EFFECTS. 112.11. *Pinus taeda.*

OBJECT: To produce new and more useful trees through chromosomal aberrations and mutations.

METHODS: Seven seed lots were treated with seven dosage levels of gamma irradiation in a cobalt irradiator at Oak Ridge, Tennessee. The dosages were 500r (roentgen units), 1,000r, 1,500r, 2,000r, 2,500r, 3,000r, and 3,500r. The treatments above 1,500r were apparently too heavy and no seedlings were produced. Seedlings from the three lightest dosages and a check were planted in four blocks at each of two locations. Individual plots contained 49 trees each. The plantations were made in 1955 in the Crossett Experimental Forest area on loess over coastal plain soil.

COOPERATOR: Georgia-Pacific Corp.

ASSIGNMENT: Hoy C. Grigsby, Associate Plant Geneticist.

27—14. THE TREATMENT OF PINE SEED WITH X-RAYS TO INDUCE POSSIBLE CYTOGENETIC EFFECTS. 112.11. *Pinus taeda.*

OBJECT: To produce chromosomal aberrations and mutations.

METHODS: The five levels of X-ray treatment are 200r (roentgen units), 400r, 600r, 800r, and 1,000r. The first outplanting was made in 1955 in three blocks. Ten trees from each of the five treatments plus a control were planted in each block. The second outplantings were made in 1956 in two plantations. The larger plantation contained 40 trees from each of the five treatments plus the control divided into four blocks of 10 trees each. The smaller plot containing five trees from each treatment was established as a demonstration plot. The plantations are in the Crossett Experimental Forest on loess over coastal plain soil.

ASSIGNMENT: Hoy C. Grigsby, Associate Plant Geneticist.

27—15. THE EFFECT OF COLCHICINE SOLUTIONS ON LOBLOLLY PINE SEED. 112.12. *Pinus taeda.*

OBJECT: To develop new and more useful trees by attempting to induce changes in the genetic makeup of the cell.

METHODS: Stratified and unstratified lots of seed were treated from one to seven days in a 0.455 percent aqueous solution of amorphous colchicine. The seedlings were outplanted in 1954 in a single plot. Trees resulting from various treatments were randomized. Additional lots of seed were treated in the same solution the following year for periods of 1, 3, and 7 days. Seedlings from these treatments were planted in one plot in randomized rows, 10 seedlings per row. The plantations are in the Crossett Experimental Forest on loess over coastal plain soil.

COOPERATOR: Georgia-Pacific Corp.

ASSIGNMENT: Hoy C. Grigsby, Associate Plant Geneticist.

27—16. ROOTING OF LOBLOLLY PINE CUTTINGS. 151.02. *Pinus taeda.*

OBJECT: A series of short-term studies to find the optimum environmental conditions for rooting cuttings.

METHODS: Cuttings are placed in greenhouse benches and the following factors are varied to determine optimum rooting conditions: misting cycle and duration of mist, air and rooting medium temperatures, and rooting medium materials. Indolebutyric acid in various concentrations is used as the principal rooting stimulant.

COOPERATOR: Georgia-Pacific Corp.

ASSIGNMENT: Hoy C. Grigsby, Associate Plant Geneticist.

27—17. TIP MOTH INJURY IN RELATION TO TREE GROWTH. 152.0. *Pinus taeda, P. echinata, P. echinata* x *P. elliottii.*

OBJECT: To determine what effect the Nantucket tip moth (*Rhyacionia frustrana* Comstock) has on the growth and form of loblolly shortleaf, and shortleaf x slash hybrid pines.

METHODS: Tip-moth-free plots and tip-moth-infested plots are each replicated three times for all sources. The insect-free plots are sprayed twice monthly with insecticides. Installed in spring of 1959. Examinations are made yearly. This is a part of a larger study (FS-2-i16-5-SS) conducted by the U. S. Forest Service, Insect Laboratory, Gulfport, Mississippi.

COOPERATORS: Bradley-Southern Division, Potlatch Forest, Inc., and U. S. Forest Service, Forest Insect Research Project, Gulfport, Mississippi.

ASSIGNMENT: Charles X. Grano, Research Forester; Hoy C. Grigsby, Associate Plant Geneticist.

28. UNITED STATES FOREST SERVICE, SOUTHERN FOREST EXPERIMENT STATION, INSTITUTE OF FOREST GENETICS

Gulfport, Mississippi

28—1. NON-NATIVE TAXON TRIALS. 111.0, 114. *Pinus* spp.

OBJECT: To establish a source of materials for study of character variations for phylogenetic and breeding purposes, and for producing readily available germ plasms.

METHODS: Unreplicated plots of 25 seedlings spaced at 10 x 10 have been established on the Harrison Experimental Forest since 1954 with new plots being added as seedlings become available. Efforts are being made to obtain the most likely suitable sources of seed from as many *Pinus* species as possible. Any promising species or races are to be tested more extensively in separate areas. Thus far, 39 species and non-native taxa have been planted.

ASSIGNMENT: D. M. Schmitt, Associate Research Forester; J. C. Barber, Project Leader.

28—2. SELECTION, TESTING, AND BREEDING SOUTHERN PINES RESISTANT TO THE SOUTHERN PINE BEETLE. 111.0, 111.3, 152.0. *Pinus* spp.

OBJECT: (1) To select from severe beetle-outbreak areas pines that have resisted beetle attack and survived; (2) to examine components of oleoresin for possible resistance factors; and (3) to establish both open- and controlled-pollinated progeny tests to study resistance mechanisms.

METHODS: Trees that have been attacked by southern pine beetle and successfully resisted the attack are being selected throughout the South and are propagated in Mississippi and Texas by grafting. Oleoresin samples are collected from the trees for analysis, and cones harvested for open-pollinated seed. Samples are also taken from nearby trees, presumed beetle-susceptible, for controls. Oleoresin samples are analyzed by gas chromatography for either qualitative or quantitative differences in composition. Samples from open-pollinated progenies will be analyzed for estimating inheritance. Controlled crosses will be made on grafts as soon as flowers are available. Toxicity and attractiveness of whole-gum and gum component samples will be evaluated with caged populations of southern pine beetle.

COOPERATOR: J. P. van Buijtenen, Forest Geneticist, Texas Forest Service.

ASSIGNMENT: J. F. Coyne, Associate Entomologist; J. C. Barber, Project Leader.

28—3. GAS EXCHANGE IN EXCISED PINE NEEDLES. 111.0, 111.1, 111.3, 151.0. *Pinus echinata, P. taeda, P. palustris, P. elliottii.*

OBJECT: (1) To correlate the response patterns of gas exchange with tree development and growth, and (2) to determine how different genetic material may differ in its response to environmental change.

METHODS: The response patterns of gas

exchange (primarily O_2 production) of excised pine needles, measured manometrically, are being followed throughout the year in three series of experiments: (1) geographic source series (plant material is from Texas and New Jersey shortleaf pines growing in a 7-year-old seed-source plantation); (2) species series (plant material is from loblolly, slash, longleaf, and shortleaf pine saplings); (3) individual trees (plant material will be from fast- and slow-growing slash or longleaf pines). In addition, a series of experiments is being conducted to determine physiological mechanisms responsible for the observed response patterns.

ASSIGNMENT: R. M. Allen, Plant Physiologist.

28—4. LOBLOLLY PINE SEED SOURCE STUDY. 111.1. *Pinus taeda.*

OBJECT: To establish a planting of loblolly pine for sampling and breeding materials that represent different geographic regions throughout its natural range.

METHODS: Thirteen sources of seed are represented in three randomized blocks in this 6-acre planting on the Mississippi Gulf Coastal Plain. The plots are 11 x 11 trees spaced at 6 x 8, the internal 49 trees serving as the sampling plot, and were planted in spring, 1960. A row of demonstration plots was planted in the spring, 1959.

ASSIGNMENT: O. O. Wells, Associate Geneticist.

28—5. RACIAL VARIATION IN ROOT TYPES OF LONGLEAF PINE. 111.1. *Pinus palustris.*

OBJECT: (1) To determine the extent and types of root form variations; (2) to determine if a reported diffuse-rooted Georgia type could be identified; and (3) to measure effects of differences in root form on subsequent growth and other characters.

METHODS: About 1100 trees were outplanted on the Harrison Experimental Forest in 1959. The trees are from seed of 72 wind-pollinated parents collected from 21 Georgia locations, Birmingham, Alabama, and other locations in the South. The planting is a 5-tree-row plot, 3-replicate, rectangular lattice design spaced 6 x 12. The trees are sprayed with Bordeaux mixture to control brown spot.

ASSIGNMENT: O. O. Wells, Associate Geneticist.

28—6. SOUTHWIDE PINE SEED SOURCE STUDY. 111.1. *Pinus taeda, P. elliottii, P. palustris, P. echinata.*

OBJECT: To map, for longleaf, slash, loblolly, and shortleaf pines, the zones within which seed may be moved freely from collecting ground to planting site, but across the boundaries of which it should not be moved.

METHODS: The Southwide Pine Seed Source Study was initiated in 1951 by the Committee on Southern Forest Tree Improvement. State, industrial, federal, school, and private individual cooperators in 16 states have established 128 plantations in connection with the study. Of these, 108 are being maintained, and include 2,780 plots, 136,220 measurement trees, and 336,380 trees in all—less mortality. In addition to having installed them, the cooperators maintain, protect, and periodically remeasure the plantations, in selected instances with supplementary insect and disease re-examinations by Forest Experiment Station specialists. In addition to the cooperating planters, many agencies, particularly the State Forest Nurseries, cooperated in the production of the planting stock, and many more, including several private individuals, contributed seed for the study. Several cooperators have included extra plantations, or taken additional measurement data in their standard plantations to get further information from the study. Such activities are encouraged. Although a member of the Southern Forest Experiment Station staff is Chairman of the Subcommittee coordinating the study, and devotes 50 to 75 percent of his time, plus clerical help, to the undertaking, it must be emphasized that this is not a U. S. Forest Service study. It is an enterprise of the Committee on Southern Forest Tree Improvement, in which the Forest Service (through the Northeastern, Southeastern, Southern, and Central States Forest Experiment Stations and their Research Projects, and Region 8 through two of its National Forests) is merely one of many cooperators. Individual cooperators have the privilege of publishing independently the results from plantations or groups of plantations under their own care and jurisdiction, but the Committee on Southern

Forest Tree Improvement reserves review and publication rights on combinations of plantations of two or more cooperators.

COOPERATORS: Individuals and agencies in 16 states.

ASSIGNMENT: Subcommittee on Geographic Source of Seed, O. O. Wells, Chairman, Gulfport, Mississippi.

28—7. CROSSES OF SLASH PINE ON VARIOUS SHORTLEAF RACES. 111.1, 112.01. *Pinus elliottii, P. echinata.*

OBJECT: This study is designed to test, through most of the range of shortleaf pine, hybrids between slash pine of a single provenance and shortleaf pine of eight different provenances. The various shortleaf x slash combinations and their checks will be compared in terms of survival, cold resistance, drought resistance, growth rate, resistance to fusiform rust, recovery from tip-moth damage, and susceptibility to littleleaf disease to see whether the hybrids can be specifically tailored to the requirements of different planting localities by choosing shortleaf parents of appropriate provenances.

METHODS: The hybrid seed was produced from controlled pollinations made by the Southern Station and Hodges Land and Timber Company, Inc., in 1960 and 1961. Seed has been shared among the Northeastern, Southeastern, Central States, and Southern Forest Experiment Stations and the Tennessee Valley Authority. Seedlings grown by these cooperating agencies during 1963 were planted during the 1963-64 planting season in six replications of 15-tree row-plots in New Jersey, Pennsylvania, Ohio, Arkansas, Louisiana, Mississippi, and Georgia, and in four replications of 7-row × 7-tree plots on a littleleaf site in Alabama. Slash pine of the same provenance as the pollen parents of the hybrids, and shortleaf pine local to each planting site, were included as checks. A second large-plot planting was established in Georgia in December 1964 on a littleleaf site.

COOPERATORS: A. J. Hodges Forest Products Co., Inc.; Northeastern Forest Experiment Station; Central States Forest Experiment Station; Southeastern Forest Experiment Station; Southern Forest Experiment Station; Tennessee Valley Authority.

ASSIGNMENT: Coordinated by O. O. Wells, Associate Geneticist.

28—8. THE NATURE OF SLASH PINE ON THE MISSISSIPPI AND ALABAMA OFFSHORE ISLANDS. 111.1 *Pinus elliottii.*

OBJECT: To study morphological variations between island, coastal, and inland populations.

METHODS: Trees on Cat, Horn, and Dauphin Islands were sampled for needle, bud, twig, and cone characters. Samples were also taken from trees on the mainland beaches opposite each island, trees along a transect running north from the coast, and from a coastal progeny growing on the experimental forest.

COOPERATOR: Francois Mergen, Professor, Yale University.

ASSIGNMENT: E. B. Snyder, Geneticist.

28—9. GEOGRAPHIC VARIATION IN NEEDLE CHARACTERISTICS OF LOBLOLLY AND SHORTLEAF PINE. 111.1. *Pinus taeda, P. echinata.*

OBJECT: To determine the geographic pattern of genetic variation in needle characteristics of loblolly and shortleaf pines.

METHODS: Needles from 44 widely distributed seed sources will be studied using Southwide Pine Seed Source Study material growing in Harrison and Pearl River Counties, Mississippi, and in Washington Parish, Louisiana. Twenty-two anatomical and morphological characters are being examined.

COOPERATOR: Francois Mergen, Professor, Yale University.

ASSIGNMENT: O. O. Wells, Associate Geneticist.

28—10. BREEDING IN SLASH PINE PLANTATIONS OF NON-LOCAL SEED SOURCE. 111.1, 111.3. *Pinus elliottii.*

OBJECT: To compare progeny from local natural sources to those from a Florida seed source plantation. The information is needed to evaluate the feasibility of further genetic and breeding research within such plantations which are widespread in the south.

METHODS: Wind-pollinated progeny from 64 trees from the two sources, were outplanted in 1956. About 1900 trees were planted on each of two 3-acre sites: the Harrison Experimental Forest and the McNeill Experimental Forest. At each location a 3-replicate, 10-tree-row plot, triple lattice design was used with 6 x 12 spacing.

ASSIGNMENT: E. B. Snyder, Geneticist.

28—11. SLASH × SHORTLEAF F_1 HYBRID. 111.1, 111.3, 112.01. *Pinus elliottii, P. echinata.*

OBJECT: (1) To estimate the influence of pollen source and individual seed parent upon the frequency of nanophytes in the F_1 hybrid populations of slash x shortleaf, and (2) to compare variation patterns in mortality and height growth of the hybrid progenies with those of open-pollinated progenies from the same seed parents.

METHODS: Shortleaf pollen sources of different geographic origin have been used to control-pollinate selected Florida slash pine trees. Control-pollinated and open-pollinated seed will be collected to provide the progenies required. Single-tree replicated plots, 6-foot triangular spacing, in compact family block design will constitute the outplanting. Nanophytes will be statistically defined and the appropriate frequency distributions compared. Height growth, its variance, and mortality comparisons will also be made.

ASSIGNMENT: D. M. Schmitt, Associate Research Forester.

28—12. *Pinus rigida* TESTS. 111.1, 112.01. *Pinus rigida.*

OBJECT: To test the local adaptability of *P. rigida* and *P. rigida* hybrids when crossed and compared with *P. echinata, P. serotina, P. taeda,* and *P. glabra.*

METHODS: Two hundred and sixty-five trees representing various *P. rigida* and test crosses are to be planted on each of two harsh sites, very wet and very dry, on the Harrison Experimental Forest. Due to the extremely variable number of seedlings representing the various crosses, complete randomization of single tree plots, spaced at 8 x 8 will be used.

ASSIGNMENT: D. M. Schmitt, Associate Research Forester.

28—13. RECIPROCAL SPECIES EFFECTS IN SHORTLEAF X SLASH AND SLASH X SHORTLEAF HYBRIDS. 111.1, 112.01. *Pinus elliottii, P. echinata.*

OBJECT: To test, in two locations, hybrids between slash pine and shortleaf pine from eight widely distributed seed sources. The assumption that each species of the cross contributes equally to the genetic constitution of the hybrid will be tested by this study.

METHODS: Hybrids were produced by controlled pollination with both slash pine and shortleaf pine used first as male and then as female parents. Plantings were established in Jasper County, Georgia, and Harrison County, Mississippi, during the 1963-1964 planting season.

COOPERATOR: Southeastern Forest Experiment Station.

ASSIGNMENT: O. O. Wells, Associate Geneticist.

28—14. EFFECT OF THE ROOTS ON THE HEIGHT GROWTH OF PINES. 111.1, 151.0. *Pinus taeda, P. elliottii, P. echinata.*

OBJECT: To measure the variation in height growth which can be attributed to differences in root efficiency and vigor.

METHODS: In two studies the tops and roots of young loblolly, slash, and shortleaf seedlings were interchanged in all combinations by grafting. The outplantings have 8 single-tree replications of each combination in one study and 10 in the other. Double-root systems were made by inarching in a thrid study. Here again all three species are represented in all combinations and there are 10 single-tree replicates in the outplanting. In a fourth study there are four treatments: (1) Scions from seven geographic sources of shortleaf grafted on the local shortleaf rootstock, (2) shortleaf source scions grafted on slash rootstock, (3) scions from the local shortleaf source grafted on the rootstocks of the other sources, and (4) shortleaf scions grafted on rootstocks of their own source. There are 10 single-tree replicates in the outplanting. Annual measurements will be made for at least five years.

ASSIGNMENT: R. M. Allen, Plant Physiologist.

28—15. SELECTION OF FAST-GROWING SLASH AND LOBLOLLY SEEDLINGS FROM THE ASHE NURSERY. 111.3. *Pinus taeda, P. elliottii.*

OBJECT: To obtain a future source of valuable variants for physiological and genetic studies and for tree improvement research.

METHODS: Annual selections for a 10-year period ending in 1971 are outplanted with controls. Selection intensity is approximately one per nursery bed (1:50,000).

ASSIGNMENT: E. B. Snyder, Geneticist.

28—16. PROGENY TESTING LONGLEAF PINE FOR BROWN-SPOT RESISTANCE. 111.3. *Pinus palustris.*

OBJECT: To identify brown-spot-resistant longleaf pines.

METHODS: Open-pollinated seed from 543 longleaf trees were collected and seedlings grown at Alexandria, Louisiana, and Gulfport, Mississippi. Bulk longleaf seedlings were planted 1 year earlier in Mississippi than selected progenies to build up a heavy inoculum on the area. Progenies were planted in single-tree plots with 10 replicates at three locations (Alexandria, La., and two in Harrison County, Miss.); one location in Mississippi will be sprayed to control the disease for a comparison of growth. Brown-spot infection and heights will be recorded up to 4 years.

COOPERATOR: Crown-Zellerbach Corp.; International Paper Company; Southeastern Forest Experiment Station.

ASSIGNMENT: Harold J. Derr, Research Forester, Alexandria, La.; F. F. Jewell, Plant Pathologist.

28—17. PROGENY OF INDIVIDUAL LONGLEAF PINE TREES. 111.3. *Pinus palustris.*

OBJECT: To determine if there is any variation in the length of the grass stage period between the progeny of individual, wind-pollinated longleaf trees in south Mississippi.

METHODS: Wind-pollinated longleaf seed was collected from 35 different trees each year for 4 years. Part of the trees in the last 3 years' collection were located in Pearl River County, Mississippi, part in Harrison County, Mississippi, and part in Stone, Forrest, or Perry Counties, Mississippi. The first year's collection was all from Harrison County. The stock was uniformly treated in the nursery. Field plantings have used 25-seedling row plots and a randomized complete block design. Each year's collection was a separate experiment. Survival measurements were made after 1 year in the field and survival and growth measurements each year thereafter for 2-4 years. Final field measurements have been made.

ASSIGNMENT: R. M. Allen, Plant Physiologist.

28—18. BREEDING AND PROGENY TESTING SOUTHERN PINES FOR RESISTANCE TO TIP MOTHS. 111.3, 112.02, 141. *Pinus* spp.

OBJECT: (1) To determine whether there is inherent resistance to tip moths in susceptible native species, and (2) whether resistance can be developed in susceptible native species by breeding with resistant individuals or by hybridization with resistant species.

METHODS: Individual trees indicating possible resistance to or tolerance of tip moth attack will be selected in the Southwide Pine Geographic Seed Source Study plantation on Crown-Zellerbach Corporation land near Millard, Mississippi. Other resistant trees which are reported will be investigated for possible selection. These trees will be used as parent trees in a breeding program. Hybrids developed at the Institute of Forest Genetics will be subjected to tip moth attack in the field and an evaluation made of their resistance.

ASSIGNMENT: J. F. Coyne, Associate Entomologist.

28—19. HYPOCOTYL AND COTYLEDON COLOR VARIANTS IN CROSSES OF SLASH PINE. 111.3, 112.02, 112.03, 141. *Pinus elliottii.*

OBJECT: To determine inheritance of pigmentation mutants for use in studying the genetic stand structure, inbreeding in seed orchards, ploidy and mutation breeding, species hybrids, and population genetics.

METHODS: Fourteen known carriers were intercrossed and selfed. In 1965, seedlings were studied in the nursery and in the laboratory for incidence of pink or green hypocotyls and their intergrades, and for xantha or other variants in the cotyledons. These supplement earlier studies with wind-pollinated material.

COOPERATOR: Francois Mergen, Professor, Yale University.

ASSIGNMENT: E. B. Snyder, Geneticist.

28—20. ERAMBERT'S HYBRID. 111.3, 141. *Pinus* x *sondereggeri*.

OBJECT: (1) To determine the species from which the natural hybrid originated, and (2) to test the significance of the extreme variability known to exist in its progeny.

METHODS: Samples from the parent tree and its progeny will reveal the species nature of the hybrid, and the use of variance as a variable will determine the possible existence of a significantly greater degree of progeny variability. The tree is at present considered to be a Sonderegger and as such is planted with the other Sonderegger pines.

ASSIGNMENT: D. M. Schmitt, Associate Research Forester.

28—21. VARIATION IN SHADE TOLERANCE AND WATER EFFICIENCY OF PROGENIES OF INDIVIDUAL SLASH PINES. 111.3, 141, 151.0. *Pinus elliottii*.

OBJECT: (1) To determine if there is demonstrable genetic variation in the shade tolerance of slash pine seedlings; (2) to determine if there is demonstrable genetic variation in the water efficiency of slash pine seedlings; and (3) to determine how some of the more obvious physiological mechanisms are correlated with the variations in shade tolerance and water efficiency.

METHODS: One-parent progeny from over 200 mother trees in 13 locations were tested in the nursery bed for 2 years under different levels of light intensity and soil moisture. A factorial experiment in a randomized block design with four replications was used in comparing the following treatment effects on the progeny: (1) full sunlight-high moisture; (2) full sunlight-low moisture; (3) shade-high moisture; and (4) shade-low moisture. Height measurements were made at the end of the first growing season. In the second growing season the length of the spring flush was measured. At the end of the second growing season total heights and groundline diameter were taken on all seedlings; dry weights of foliage and dry weights of stem tissue were measured on selected progeny groups. Physiological studies concerning chlorophyll content, photosynthetic and respiration rates, and measurements of relative turgidity were made. Field and laboratory work have been completed and the data are being analyzed.

ASSIGNMENT: R. M. Allen, Plant Physiologist; E. B. Snyder, Geneticist.

28—22. SELECTION AND CARE OF FUSIFORM-RUST-FREE SLASH PINES FROM CERTAIN HIGH-RUST-INCIDENCE PLOTS. 111.3, 151.01, 151.5. *Pinus elliottii*.

OBJECT: To select and maintain rust-free slash pines in plots in the Chickasawhay Ranger District of the DeSoto National Forest. A secondary object is to observe effect of certain cultural treatments on the flower production of the selected trees.

METHODS: An examination of all living plot trees was made for rust infection and the infection percent calculated. The trees were 12-18 years of age and the plot size was 1/10 acre. Four of 7 plots were selected for use having an average of 93 percent rust-infected trees present. Where possible, all rust-free trees were released by removal of adjoining trees in a 25 foot radius from each selection. Included on each plot were two selections badly rust-infected. A total of 23 rust-free and 8 rust-infected trees were selected. Following release, 20-25 pounds of 5-10-5 commercial fertilizer was applied around the base of each residual tree for two consecutive years. It is to be repeated periodically. Brush control by herbicides has been started. When the trees are of sufficient size and have adequate flowers, controlled breeding will be done.

ASSIGNMENT: F. F. Jewell, Plant Pathologist.

28—23. HISTOCHEMICAL AND BIOCHEMICAL DIFFERENCES ASSOCIATED WITH RESISTANCE TO THE FUSIFORM RUST FUNGUS IN SLASH AND SHORTLEAF PINES. 111.3, 151.5. *Pinus elliottii, P. echinata.*

OBJECT: (1) To make biochemical analyses of rust-susceptible and resistant slash pine and resistant shortleaf pine; (2) to identify by biochemical and histochemical analyses the response of pine hosts to inoculation and subsequent infection by fusiform rust; and (3) to isolate and identify chemical differences associated with resistance.

METHODS: Primary and secondary tissues of resistant and susceptible slash pines and resistant shortleaf pines will be inoculated by hypodermic injection of spores. Tissues will be sampled periodically and analyzed for biochemical differences. Determinations will be made for compounds such as gibberellins, auxins, auxinase, phenolics, and phenoloxidase. Tissue samples also will be quick-frozen, sectioned, and stained with vital stains to determine changes at the cellular level and locate response mechanisms to infection.

ASSIGNMENT: R. C. Hare, Associate Plant Physiologist.

28—24. CONVERSION OF EARLY BOGALUSA PINE PLANTATIONS TO BREEDING BLOCKS, WITH ANALYSIS OF RELATIONSHIP BETWEEN JUVENILE AND MATURE PHENOTYPIC CHARACTERS. 111.3, 153. *Pinus taeda, P. elliottii, P. palustris, P. echinata.*

OBJECT: (1) To utilize individual-tree measurements and descriptions at ages of 1, 2, 3, 4, 5, 10, 15, and 30 years in plantations of four species on two to six soil types each, for study of the variation in height and diameter at different ages; (2) to establish juvenile-mature correlations; and (3) to estimate predictive value of juvenile traits for use in early selection.

METHODS: Individual-tree measurements and descriptions had been made at various ages from 1 to 30 years on the survivors of 23,000 trees planted 1922-26. Four species on several sites are included. At age 30 final selection of more than 200 trees (plus corresponding checks) were made on a basis of "mature" performance and prior juvenile selections at ages 3-5. Data will be analyzed to determine variation at different ages, changes in stand structure, juvenile-mature correlations, species-soil interactions, etc. The value of various juvenile selection criteria will be examined. Selected trees have been released to increase flower production. These trees will be used in other genetic studies.

COOPERATOR: Crown-Zellerbach Corporation and predecessors have assisted in all phases of the study since its establishment.

ASSIGNMENT: Philip C. Wakeley, Principal Research Forester.

28—35. HALF-SIB PROGENY TESTS WITH MISSISSIPPI FOREST TREES. 111.3, 211.3. *Pinus taeda, Liquidambar styraciflua.*

OBJECT: To determine genetic variation attributable to range-wide, state-wide, stand, and individual tree effects in loblolly pine and sweetgum.

METHODS: Range-wide collections of loblolly pine seed have been grown under controlled environmental conditions. Morphological characters of seed and seedlings, and responses of seedlings to various environmental conditions are being studied. In a second phase of the study seed collected from five trees in each of 137 sweetgum and 118 loblolly stands along 20 latitudinal transects will be outplanted on several sites in Mississippi. Sources are from western Alabama to west of the Mississippi River, and north from the Gulf to the limit of the natural range of loblolly pine. The study is part of the S-23 project.

COOPERATOR: Mississippi State University.

ASSIGNMENT: George L. Switzer, Professor, Mississippi State University; O. O. Wells, Associate Plant Geneticist; J. R. Wilcox, Associate Plant Geneticist.

28—26. SONDEREGGER PINE PLANTATION, 1926-27. 112.01. *Pinus* x *sondereggeri.*

OBJECT: To observe the normal development of putative F_1 *Pinus palustris* × *P. taeda* (Sonderegger pine) from longleaf pine seedbeds.

METHODS: Some 330 hybrid seedlings were selected from longleaf seedbeds sown with local seed, outplanted 6 x 8 in 1926-27, and remeasured periodically. Initial survival approximated 95 percent. Site was adverse, survival at age 30 approximately 16 percent. Growth, form, and infection by fusiform rust were highly variable. The plantation was supplemented by one control-pollinated backcross of *P. palustris* on putative F_1 *P. palustris* x *P. taeda*. Study is located at Bogalusa, Washington Parish, Louisiana ("Coburn's Creek"), on upper coastal plain site.

COOPERATOR: Crown-Zellerbach Corporation.

ASSIGNMENT: D. M. Schmitt, Associate Research Forester.

28—27. BREEDING AND PROGENY TESTING FOR RESISTANCE TO FUSIFORM RUST IN SOUTHERN PINES. 112.01, 112.02, 151.5. *Pinus elliottii, P. taeda, P. palustris, P. echinata.*

OBJECT: (1) Through control-breeding, both intra- and interspecific, among slash, loblolly, longleaf, and shortleaf pines to develop fusiform rust-resistant progeny lines; (2) through intensive testing by artificial rust inoculation methods, determine the reaction of 1-parent and hybrid progenies arising from objective 1; and (3) establish field plots of selected progeny lines to determine their reaction to rust infection under natural conditions.

METHODS: Selected parents of slash and loblolly are crossed intra- and interspecifically, not only among and between these two species but also with shortleaf. Slash and longleaf pine have been crossed by controlled means. Progenies are tested in the nursery using a randomized block design. Examination of the seedlings is made 8-9 months following inoculation, and those free of rust are potted, held till the following spring, and reinoculated. Suitable statistical analysis is made of the results.

ASSIGNMENT: F. F. Jewell, Plant Pathologist.

28—28. EFFECTS OF PHENOTYPIC VARIATION OF PARENTS UPON HYBRID PROGENIES. 112.01, 141. *Pinus elliottii, P. palustris, P. taeda.*

OBJECT: To investigate the components of variation attributable to individual parent trees in the over-all species hybrid variation.

METHODS: Three trees exhibiting gross morphological differences among themselves were selected from each of the three species, *P. elliottii* var. *elliottii, P. palustris,* and *P. taeda* for interspecies breeding. Hybrids were among all species. Several characters, particularly form and vigor, are to be followed in the nursery and field. The planting design will be in 5 to 10-tree row plots in compact family blocks, replicated 6 times.

ASSIGNMENT: D. M. Schmitt, Associate Research Forester.

28—29. SONDEREGGER PINE. 112.01, 141. *Pinus × Sondereggeri.*

OBJECT: (1) To determine the inheritance of characters of discriminatory and economic value in natural and artificially produced populations of *P. × Sondereggeri,* and (2) to determine the extent of introgression.

METHODS: Samples have been taken from two hybrid swarm areas in east Texas and west Louisiana, two planted populations in Louisiana, several plots of F_1 *P. × sondereggeri* in Mississippi, and from isolated trees throughout the South. A 3,600-tree planting of various Sonderegger back crosses has been established at the Harrison Experimental Forest at a 6 x 12 spacing, using 20-tree row plots arranged in compact family blocks and replicated 6 times. Further samplings and controlled pollinations are being made.

ASSIGNMENT: D. M. Schmitt, Associate Research Forester.

28—30. INTERSPECIES HYBRID ARBORETA. 112.01, 141. *Pinus* spp.

OBJECT: (1) To explore interspecies and self-compatibilities, (2) to study inheritance patterns of the southern pine hybrids.

METHODS: The following hybrids resulting from 1954 pollinations have been planted in Harrison County, Mississippi: *P. palustris* x *P. elliottii elliottii, P. palustris* x *P.* x *sondereggeri, P. palustris* x *P. taeda, P. palustris* x (*P. echinata* x *P. elliottii elliottii*), *P. palustris* x (*P. palustris* x *P. taeda*), *P. elliottii elliottii* x

P. taeda, P. taeda x *P. elliottii elliottii, P. taeda* x *P.* x *sondereggeri, P. echinata* x *P. elliottii elliottii, P. echinata* x *P. taeda, P. echinata* x *(P. echinata* x *P. elliottii elliottii), P.* x *sondereggeri* x *P. taeda,* and *P.* x *sondereggeri* x (*P. echinata* x *P. elliottii elliottii*). One thousand two hundred and fifty-two seedlings were originally planted 12 x 12 in three replications with up to 16 trees per row plot, of which 1069 survived their second year in the field. This material has been measured for early height and diameter growth and pest occurrence and is being used for sample materials in studies of hybrid inheritance. Since flowering has started, various backcross combinations are being made on a small scale. A second hybrid test area was established in 1959 with 1120 trees at 6 x 10 in 10-tree row plots in 7 randomized blocks.

ASSIGNMENT: D. M. Schmitt, Associate Research Forester.

28—31. BREEDING WITH A HIGH SPECIFIC GRAVITY LONGLEAF PINE. 112.02. *Pinus palustris.*

OBJECT: (1) To determine to what degree the high specific gravity of the selected tree (Wayne 1-1) is heritable and how much regression toward the mean will occur; (2) to determine to what type of parents this tree should be mated to capitalize on this outstanding trait, i. e., can it be combined with a tree of outstanding form, etc. to get better progeny; and (3) to determine how soon superior combinations can be recognized and whether there are correlated traits such as straightness and form.

METHODS: Wayne 1-1 was mated with four other trees selected for specific characteristics such as form, growth rate, crown, limbiness, etc. Parent tree measurements will be recorded, fiber lengths will be determined, and the trees will be vegetatively propagated. The 400 progeny were outplanted at 12 x 12 triangular spacing in 1963. There were 10 replicates of 10-tree row plots in a randomized block design. Progeny first-year field survivals will be recorded, as will the 3, 5, 10, etc. year heights. D.b.h. and form estimates will be recorded as soon as measurable. Wood quality tests will begin in the juvenile state for comparisons with mature measurements.

ASSIGNMENT: E. B. Snyder, Geneticist.

28—32. CONTROLLED POLLINATIONS FOR STUDYING INHERITANCE OF VIGOR, FORM, AND SEXUALITY IN SLASH PINE. 112.02, 141. *Pinus elliottii.*

OBJECT: To study the inheritance of certain phenotypic variants occurring in a 4-acre slash pine plantation.

METHODS: About 2000 trees from controlled crosses among eight parents were planted in 1959. A compact family block design was used with three replications, and 10-tree row plots (multiple plots per entry per replication were used for some depending on the number of seedlings available). Spacing was 6 x 12.

ASSIGNMENT: E. B. Snyder, Geneticist.

28—33. PARENT HALF-SIB RELATIONS WITH RESPECT TO VIGOR, SEED SIZE, AND OTHER CHARACTERISTICS IN LONGLEAF PINE. 112.02, 141. *Pinus palustris.*

OBJECT: To obtain information on heritability of growth rate, seed size, variation in brown spot reaction, and other characters, and to show how such information can be used for genetic models and development of selection methods.

METHODS: Two plantings have been made on the Harrison Experimental Forest: (1) About 3000 seedlings survived from a 1957 outplanting of 8 acres. They are progeny from the wind-pollinated seed of 100 randomly selected trees. The planting is an 8-tree row plot, 6-replicate, triple lattice design. The planting was 6 x 12. It was sprayed with Bordeaux mixture. (2) The planting was repeated in 1958 on 1 acre of land but the spacing was 1½ x 12 and the planting was an 8-tree row plot, 2-replicate, simple lattice. It is left unsprayed to determine the brown spot reaction of the progeny.

ASSIGNMENT: E. B. Snyder, Geneticist.

28—34. VARIATION AND INHERITANCE OF SEED CHARACTERS OF LONGLEAF-LIKE PINES. 112.02, 141. *Pinus palustris.*

OBJECT: (1) To study the inheritance of the black seed-coat and loose-wing characters in longleaf (?) pine; (2) to study the possible use of these characters as chromosome markers; and (3) to test the hypothesis of homologous variation against that of introgression as an explanation of these characters.

METHODS: About 2500 seedlings, mostly backcrosses, were outplanted in 1964 in five randomized blocks of 10-tree plots. About 500 F_1's are available from earlier plantings. Cultural measures will be taken to hasten flowering.

COOPERATORS: West Louisiana Land and Timber Co., Inc., Many, La.; Southern Forest Experiment Station, Alexandria, La.

ASSIGNMENT: E. B. Snyder, Geneticist.

28—35. CONTROL POLLINATING AND PROGENY TESTING PLUS SLASH PINE SELECTION, 1958. 112.02, 141. *Pinus elliottii.*

OBJECT: (1) To verify phenotypic characteristics of plus trees and to obtain and evaluate certain F_1 combinations by 2-parent progeny tests; (2) to try a progeny test method which is simple and yet produces a knowledge of specific combining ability as well as the usual general combining ability; and (3) to study the inheritance of characters such as specific gravity, growth, and form.

METHODS: Twelve plus parent trees were pollinated to give 51 different crosses, excluding reciprocals. Sources for the selections of plus trees are as follows: (1) Harrison Experimental Forest—six trees selected for form, specific gravity, progeny size, volume, cone-bearing ability, and accessibility; (2) Crown-Zellerbach plantation, Bogalusa, La.—four trees selected for form, specific gravity, and growth rate; (3) International Paper Co. lands in Mississippi—two trees selected for specific gravity and growth rate. Parent trees will be as fully characterized as possible by measurements of branch characters, stem form, specific gravity, growth rate, phenology, etc. Amount of competition will be considered. The 3,300 trees of crosses and controls constituting 54 entries were outplanted on two sites at 12 x 12 triangular spacing in 1965. To accommodate variable seed yields, they were divided into (1) an 8-replicate, simple lattice of 36 entries in 9-tree rows, and (2) an 18-entry, 6-replicate, 7-tree plot randomized block. Progeny characters measured will include nursery heights, 2-year survival, and 6-year heights. The same characters measured on the parent trees will be measured on the progenies at 5-year or suitable intervals for parent-progeny regressions, among other analyses.

COOPERATORS: Crown-Zellerbach Corp.; International Paper Co.

ASSIGNMENT: E. B. Snyder, Geneticist.

28—36. COMPATIBILITY, GROWTH RATE, AND MUTANT CHARACTERS IN SELFED SLASH PINE. 112.03, 141. *Pinus elliottii.*

OBJECT: To obtain seed from enough parents to obtain valid estimates of the effects from selfing.

METHODS: Fifty pollination bags on each of 35 parents received self pollen. Selfed and wind-pollinated seedlings of each were compared in the nursery. The 800 selfed seedlings were outplanted with 800 wind-pollinated control seedlings in two 3-acre sites at 12 x 12 triangular spacing in 1965. To accommodate variable seed yields, 12 of the paired entries were divided into a 9-tree row plot, 6-replicate split-plot design, while 19 were outplanted in a 2-tree, 4-replicate split-plot.

ASSIGNMENT: E. B. Snyder, Geneticist.

28—37. X-IRRADIATION AND AGING OF SOUTHERN PINE SEED FOR HETEROTIC AND MUTAGENIC EFFECTS. 112.11. *Pinus taeda, P. echinata, P. elliottii.*

OBJECT: To study the nature of X_2 mutations.

METHODS: Results from early phases have been published. Slash, shortleaf, and loblolly planted in 1951 and 1955 from irradiated or 23-year-old seed were thinned in 1964 to induce flowering. Some of the 150 trees will be intercrossed when they flower.

ASSIGNMENT: E. B. Snyder, Geneticist.

28—38. DIALLEL CROSSES WITH LOBLOLLY PINE. 141. *Pinus taeda.*

OBJECT: To study genetic variances intensively in the southwestern range of loblolly pine.

METHODS: Within selected stands, 10 random trees are intercrossed in all combinations, excluding selfs and reciprocals. One of three stands within Mississippi has been completed and will be outplanted both in Mississippi and Texas in 1967. Crosses from other stands, including several in Texas, will be subsequently planted in both states.

COOPERATION: J. P. van Buijtenen, Texas Forest Service.

ASSIGNMENT: E. B. Snyder, Geneticist.

28—39. POLYGENIC INHERITANCE IN DIALLEL CROSSES OF LONGLEAF PINE. 141. *Pinus palustris.*

OBJECT: To determine types and relative effects of gene and environmental action, combining ability, effects from selfing, differences in reciprocals, etc. in longleaf pine.

METHODS: About 6000 seedlings from controlled pollinations among 13 trees were outplanted in 1960 on 2 sites of the Harrison Experimental Forest. There are approximately 1,500, 4-tree row plots. Whole plots contain paired reciprocal crosses and are in a 9 x 9 rectangular lattice design with eight replications. Spacing is 12 x 12 in an equilateral triangle system. The plots were sprayed semiannually with Bordeaux mixture until height growth had been initiated.

ASSIGNMENT: E. B. Snyder, Geneticist.

28—40. QUANTITATIVE GENETICS OF FOREST TREES. 141, 241. General.

OBJECT: (1) To apply theories of quantitative genetics to the special problems of breeding forest trees; (2) to relate the concepts of character development and correlations to economically oriented selection and to the genetic variability structure of natural stands of forest trees; and (3) to analyze, on the basis of present theories, proposed methods for producing genetically improved seed.

METHODS: Using data from all possible sources, examine the application of present genetics theory and plant breeding methods to the problems of forest tree breeding and genetics. Presently used methods will be critically examined in the light of their underlying assumptions and of new genetic knowledge as it becomes available. Experimental designs and study plans will be developed to test new hypotheses and to produce genetic information with maximum efficiency.

COOPERATOR: Department of Genetics, North Carolina State University.

ASSIGNMENT: Gene Namkoong, Plant Geneticist.

28—41. STUDY OF THE GROWTH SUBSTANCES IN PINE. 151.0. *Pinus taeda, P. palustris, P. elliottii.*

OBJECT: To determine the nature and role of the growth substances present in pine buds.

METHODS: Extracts of the buds of loblolly, longleaf, and slash in various stages of growth are being examined by chromatographic and bioassay procedures. The qualitative and quantitative changes in growth substances are being studied during different stages of growth. Work is also under way to identify these substances.

ASSIGNMENT: R. M. Allen, Plant Physiologist.

28—42. SOME ASPECTS OF HEIGHT GROWTH IN THE SOUTHERN PINES. 151.0. *Pinus* spp.

OBJECT: To quantify and determine how height growth and variation in height growth occur in the southern pines.

METHODS: A summary of observations and analyses, mainly by auto-correlation, of detailed height growth measurements of the southern pines made over a period of years.

ASSIGNMENT: R. M. Allen, Plant Physiologist.

28—43. FUSIFORM RUST INOCULATION OF PINE. 151.5. *Pinus elliottii.*

OBJECT: To develop techniques of rust inoculation of pine applicable to large-scale testing of hybrid progeny for resistance to fusiform rust.

METHODS: At the Harrison Experimental Forest, moist-chambers were constructed for inoculating young (30-50-day-old) slash pines *(Pinus elliottii* var. *elliottii)* in 4 x 4 nursery bed sections, and for inoculating one year or older potted plants under environmental conditions favorable for rust infection. Improvement of methods and facilities is continuing.

ASSIGNMENT: F. F. Jewell, Plant Pathologist.

28—44. OBSERVATIONS ON THE PENETRATION OF THE PINE HOST BY THE SPORIDIA OF *Cronartium fusiforme* AND THE ASSOCIATED HOST RESPONSES. 151.5. *Pinus* spp.

OBJECT: To determine through histological methods the method of penetration used by *C. fusiforme* on its pine hosts, and to study the anatomical changes resulting from successful establishment of the parasite in the host tissue, as compared with the normal anatomy of the host.

METHODS: Pine material from nursery or other artificial rust inoculations is killed, fixed, and paraffin embedded for serial sectioning. Uninoculated pine is handled in a similar manner. Microscopic examinations of the stained sections are made and details of the normal and pathological anatomy of the tissue are studied along with the morphology and developmental changes of the parasite.

COOPERATOR: R. P. True, Pathologist, West Virginia University.

ASSIGNMENT: F. F. Jewell, Plant Pathologist.

28—45. THE RELATIONSHIP OF SUSCEPTIBILITY OF PINES TO *Ceratocystis Minor* (Hedgc.) HUNT TO SUCCESSFUL ATTACK BY THE SOUTHERN PINE BEETLE. 152.0. *Pinus* spp.

OBJECT: To determine if resistance to the southern pine beetle may be related to the rate of spread of the blue stain fungus *Ceratocystis minor.*

METHODS: The blue stain fungus *C. minor* is specific to southern pine beetle. Mortality of trees is usually attributed to the interruption of water movement by the fungus rather than the girdling effect of the beetle. Trees of shortleaf, loblolly, and slash pine will be inoculated with the fungus to determine rate of spread and subsequent mortality of the trees. Progenies of beetle-resistant selections will be compared as soon as available. The effects of the fungus on oleoresin flow, pressure, and composition will be measured. An attempt will be made to relate any differences to resistance or susceptibility to beetle attack.

ASSIGNMENT: R. C. Hare, Associate Plant Physiologist.

28—46. EVALUATION OF NON-NATIVE *Liquidambar* spp. 211.0. *Liquidambar* spp.

OBJECT: To evaluate the performance of *L. formosana* and a Mexican source of *L. styraciflua* in relation to local *L. styraciflua.*

METHODS: Fifty sources of *Liquidambar,* seven of *L. styraciflua* from the United States, one from Mexico, and 42 sources of *L. formosana* have been outplanted at the Harrison Experimental Forest. There are 200 8-tree row plots at 8 x 8 spacing in a randomized block design of four replications. Thirty of the sources have also been outplanted near Greenville, Mississippi.

ASSIGNMENT: James R. Wilcox, Associate Geneticist.

28—47. GERMINATION RESPONSE OF SWEETGUM PROVENANCES TO STRATIFICATION TIME. 211.1. *Liquidambar styraciflua* L.

OBJECT: To determine the variation in stratification requirements of sweetgum seed collected throughout Mississippi and adjacent portions of adjoining states.

METHODS: Sweetgum seed was collected from three stands along each of six lines of latitude, 30-35°N, in Mississippi and adjacent portions of Alabama and Louisiana. Seed from five trees were bulked to represent each stand. Following stratification for 0, 4, 8, 16, 32, and 64 days, seed were placed in an incubator at alternating temperatures of 20°C for 16 hours and 30°C with light for eight hours. Daily germination counts were made for three weeks to study rate and total germination.

COOPERATOR: George Switzer, Professor, Mississippi State University.

ASSIGNMENT: James R. Wilcox, Associate Geneticist.

28—48. BROAD SENSE HERITABILITY ESTIMATES IN COTTONWOOD. 211.3, 241. *Populus deltoides.*

OBJECT: To obtain broad sense heritability estimates and expected gains at various selection intensities for growth and wood quality characters.

METHODS: Forty-nine randomly selected run-of-the-bar seedlings from a 3-year-old cottonwood stand were subdivided into 20-inch cuttings for inclusion in the study. Clones were field-planted in a randomized block design with six replications of single-tree plots. The site was a sharkey clay. Following first-year growth, 6-inch cuttings were taken from each clone and placed in containers of soil in a split-plot design in the lath-house to evaluate rooting ability of the clones and the effect of two soil types, sharkey clay and a standard potting mixture, on root development.

ASSIGNMENT: James R. Wilcox, Associate Geneticist; Robert E. Farmer, Jr., Associate Research Forester.

28—49. SWEETGUM HALF-SIB PROGENY EVALUATION. 211.3, 251.09. *Liquidambar styraciflua.*

OBJECT: To study the variability and inheritance of various phenological, growth, form, and wood quality characteristics of sweetgum and the influence of location on their expression.

METHODS: Progenies from 40 wind-pollinated trees selected to represent a range of phenotypes and sites were outplanted at the Harrison Experimental Forest near Gulfport and the Delta Experimental Forest near Stoneville, Mississippi. Each outplanting consists of five replications of 4-tree row plots per parent tree on a 12 x 12 equilateral spacing.

ASSIGNMENT: James R. Wilcox, Associate Geneticist; Robert E. Farmer, Jr., Associate Research Forester.

28—50. CONTROL-POLLINATION OF SWEETGUM. 254.0. *Liquidambar styraciflua.*

OBJECT: To define the period of receptivity of female flowers and to assess the amount of self-pollination in sweetgum.

METHODS: Controlled pollinations were made on emasculated, bagged sweetgum flowers on each of 3 trees at 2-day intervals from March 16-30, 1963, and from March 11-April 8, 1964. Protective bags were also placed over both male and female flowers on each tree to insure self-pollination. Seed heads were collected from controlled-pollinations, self-pollinations, unpollinated checks, and wind-pollinated flowers. Data were recorded and compared on seeds per head and seed weight for the various pollinations. Observations are continuing.

ASSIGNMENT: James R. Wilcox, Associate Geneticist.

28—51. EFFECT OF COLLECTION TIME ON SWEETGUM SEED QUALITY AND SEEDLING HEIGHT. 254.0. *Liquidambar styraciflua.*

OBJECT: To determine the effect of time of collection on sweetgum seed quality and subsequent seedling height.

METHODS: Seed heads were collected from 6 sweetgum trees in south Mississippi at 2-week intervals from September 5 to November 28, 1962. Data were recorded on specific gravity of the seed head, seed weight, and percent and rate of germination for each tree on each collection date. Percent germination and seedling height were also evaluated in a replicated nursery test.

ASSIGNMENT: James R. Wilcox, Associate Geneticist.

28—52. FORCING SWEETGUM FLOWERS. 254.0 *Liquidambar styraciflua.*

OBJECT: To evaluate the effects of several environmental factors on sweetgum flower-bud dormancy and development.

METHODS: Flower-bud-bearing sweetgum branches from each of 3 trees were collected at 3-week intervals from early January to mid-February. Collected branches were subjected to two temperature treatments, two day-length treatments, and to various nutrient and growth-promoting substances to study their effects on flower-bud break and subsequent development. Additional studies will further define optimum conditions of forcing.

ASSIGNMENT: James R. Wilcox, Associate Geneticist.

28—53. FREEZE-DRYING OF SWEETGUM AND YELLOW-POPLAR POLLEN. 254.0. *Liquidambar styraciflua, Liriodendron tulipifera.*

OBJECT: To develop optimum techniques for freeze-drying, storage, and recovery of sweetgum and yellow-poplar pollen.

METHODS: Samples of sweetgum and yellow-poplar pollen were freeze-dried under high vacuum for 0 and 30 minutes, 1, 2, 4, and 8 hours. Prior to freeze-drying, moisture content and germination percentage were determined. Treated samples were stored under vacuum at room temperature. Samples were opened immediately, after 45 days, and after 3, 6, and 12 months' storage. Pollen was checked for moisture content, then subjected to recovery treatments of 25, 50, and 100 percent relative humidity at room temperature and at 5° C. Samples from the various recovery treatments were checked at 24-hour intervals to determine germination percentage. Pollen samples will be used in pollinations to determine their effectiveness in setting seed.

ASSIGNMENT: James R. Wilcox, Associate Geneticist.

29. UNITED STATES FOREST SERVICE, SOUTHERN FOREST EXPERIMENT STATION

Harrison, Arkansas

29—1. VIRGINIA PINE PLANTATION ON SHALLOW SOILS SITES IN ARKANSAS OZARKS. 111.0 *Pinus virginiana.*

OBJECT: (1) To test the feasibility of this species as a supplement to eastern redcedar (*Juniperus virginiana* L.) on shallow limestone soils, and (2) to determine when to thin this species to achieve maximum clear growth.

METHODS: Six completely randomized blocks of two 0.1-acre plots each were planted with 1-0 Virginia pine seedlings from a northwest Pennsylvania seed source at 3 x 3 spacing in February 1957. Measurement plots of 100 seedlings were established within each of the individual plots. Should this planting be successful it is planned to thin one plot from each pair to 6 x 6 spacing 5 years after establishment. All Virginia pine crop trees on the thinned plots will be pruned leaving one-third the total height in live crown. The remaining plots will be thinned 10 years after establishment and crop trees pruned as before. Measurements will be taken after first, second, third, fifth, and every fifth growing season thereafter. The plantations are in the Henry R. Koen Experimental Forest.

ASSIGNMENT: W. R. Maple, Research Forester.

29—2. COOPERATIVE STUDY OF GEOGRAPHIC SOURCE OF LOBLOLLY PINE SEED. 111.1. *Pinus taeda.*

OBJECT: (1) To make exploratory test plantings of loblolly pine from seed lots of varied geographic source and crop years; (2) to test significant differences between sources; and (3) to demonstrate contrasting development in one planting near Norris, Tennessee.

METHOD: Three completely randomized blocks of 9 plots were established in March 1959. Four rows of four loblolly test seedlings were planted on each plot with a spacing of 8 x 8. Each plot had one row of loblolly buffer stock planted around the test stock. One row of buffer stock was planted around the three contiguous blocks, making two rows of buffer stock between all test plots. The plantation is in the Henry R. Koen Experimental Forest.

COOPERATOR: Tennessee Valley Authority.

ASSIGNMENT: W. R. Maple, Research Forester.

29—3. TEST OF HYBRID PINES. 112.01. *Pinus echinata, P. taeda.*

OBJECT: To test survival and growth of crosses of *Pinus echinata* and *P. taeda* developed by Institute of Forest Genetics, Placerville, California, within the natural range of *P. echinata* and to compare the development of the hybrids with that of the parents.

METHODS: One randomized block of twelve, 56-foot square plots was established in February 1949. Nine center trees in each plot were test trees surrounded by at least two rows of *P. echinata* buffer stock. The study was further confounded by a spacing test of 5 x 5, 6 x 6, and 8 x 8. The study plan called for three replications, but poor germination of hybrid seeds (approximately 10 percent) allowed the installation of but one block. Species and hybrids under test are: Shortleaf pine (*Pinus echinata);* loblolly pine *(P. taeda);* and shortleaf x loblolly pine hybrids, (1) 5001-1947 F_2 hybrid x *P. echinata,* (2) 5002-1947 F_2 hybrid x *P. taeda.* The plantation is on the Henry R. Koen Experimental Forest

COOPERATOR: U. S. Forest Service, Institute of Forest Genetics, Placerville, Calif.

ASSIGNMENT: W. R. Maple, Research Forester.

29—4. TEST OF CHINESE CHESTNUT, P. I. 58602. 212.01. *Castanea mollissima.*

OBJECT: To determine blight resistance, survival, growth, and adaptability to two of the better hardwood sites in the Arkansas Ozarks.

METHODS: Two ¼-acre demonstration plots of 1-0 Chinese chestnut seedlings were established on north-facing slopes derived from Boone chert and Newton sandstone. Both plots are square and contain 49 seedlings planted at 10 x 10 spacing. The plantation is on the Henry R. Koen Experimental Forest.

COOPERATOR: Crops Research Division, Agricultural Research Service, Washington, D. C.

ASSIGNMENT: W. R. Maple, Research Forester.

30. UNITED STATES FOREST SERVICE, SOUTHERN FOREST EXPERIMENT STATION

Stoneville, Mississippi

30—1. SELECTED COTTONWOOD AND HYBRID POPLAR CLONAL TRIALS, 1962 211.0, 211.3. *Populus* spp.

OBJECT: To determine if any of the new cultivars, selected for their apparent superiority over average planting stock in rooting ability, height growth, and disease resistance, are significantly better than the others and likewise better than similar material previously selected.

METHODS: There are 50 plots in a randomized block design with 5 replications. Each plot consists of one row of 10 cuttings from a single cultivar spaced 2 feet apart in the row. Rows are 3 feet apart. Basic data will consist of survival and height records taken at the end of the first growing season. Cuttings will be scored for Melampsora rust severity twice during the year. The cultivars planted and the source of stock are: I-154 (CV) (377), Hybrid, Italy; I-262 (CV) (378), Hybrid, Italy; I-214 (CV) (330), Hybrid, Italy; I-455 (CV) (331), Hybrid, Italy; Siouxland (CV), Rust resistant clone from South Dakota State College; Texas select #1 (clone), Fort Worth, Texas; Arkansas select #1 (clone), Pine Bluff, Arkansas; Alton #1 (clone), Alton, Illinois; Carbondale #1 (clone), Carbondale Research Center, Carbondale, Illinois; Run-of-the-bar (CV), Batture Experimental Forest, Chicot County, Arkansas.

ASSIGNMENT: L. C. Maisenhelder, Research Forester.

30—2. CLONAL PLANTING TEST OF SELECTED CLONES OF EUROPEAN HYBRID POPLAR AND EASTERN COTTONWOOD. 211.0, 211.3. *Populus* spp.

OBJECT: (1) To detect the presence of any elite clones of European hybrid poplar or eastern cottonwood that may be present among the planting stock selected from superior trees and now available at the Stoneville Research Center, and (2) to obtain documented survival and growth rate data for good growing stock on one of the best cottonwood-growing soils and site when given intensive cultivation and care over a 20- to 30-year period.

METHODS: There are 44 plots in a randomized block design with two replications. Each plot contains 36 trees on a 10 x 10-foot spacing. Periodic examinations will be made to observe survival, height growth, tree form, and resistance to insect and disease attack. Thinnings will be made as needed to maintain good growth throughout the life of the plantation. The European hybrids or varieties of *Populus euramericana* planted are: *bacchetierii*, var. *erecta serotina*, *eugeneii* (England), *gelrica*, *marilandica*, *mussolinii*, *regenerata* (*necroetereh*), *serotina*, I 214, *eugeneii* (Holland), *robusta* (Holland, and *Populus nigra* is included in the planting, also. In addition, there are eight selected clones of eastern cottonwood (*Populus deltoides*). The control planting is average cottonwood planting stock. An analysis of variance will determine the presence of any elite material. This study is located on Archer Island in Chicot County, Arkansas, near the city of Greenville in Washington County, Mississippi.

ASSIGNMENT: L. C. Maisenhelder, Research Forester.

30—3. TEST PLANTING, 1960, OF HYBRID POPLAR AND SELECTED CLONES OF EASTERN COTTONWOOD. 211.0, 211.3, 252.0. *Populus euramericana*, *P. nigra*, *P. deltoides*.

OBJECT: (1) To determine, over a period of 20 to 30 years, the presence of any elite clones of hybrid poplars or cottonwood among the clones now available at the Stoneville Research Center; (2) to test the use of Thimet, a systemic poison, in controlling insects; and (3) to test reduction of multiple sprouting by reducing the length of cutting exposed above the ground from 5 inches to 2 inches.

METHODS: Plots are laid out in a randomized block design with three replications. Measurements of height and diameter and records of insect and disease attacks will be made annually for the first 5 years and at 5-year intervals, thereafter. Planting stock is as follows: *Populus euramericana*, 11 varieties or hybrids; *P. nigra;* and *P. deltoides*, Catfish 1 through 5, and Rosedale 6, 7, and 8. Planting stock was obtained from 1-year-old sprouts grown in the Stoneville Research Center nursery.

ASSIGNMENT: L. C. Maisenhelder, Research Forester; J. L. Gammage, Research Technician.

30—4. YELLOW-POPLAR GEOGRAPHIC SEED SOURCE STUDY. 211.1. *Liriodendron tulipifera.*

OBJECT: To determine the extent of yellow-poplar racial variation among several different locations in the territory of the Southern Forest Experiment Station.

METHODS: Seed will be collected from the following sources: (1) A sandy site from a bay head or stream of south Mississippi; (2) a deep brown loam site in the Bluff Hills near Vicksburg; (3) a thin brown loam site near Oxford; (4) a brown loam site north of Memphis; (5) an upland brown loam site on Crowley's Ridge near Helena, Arkansas; (6) a poplar site near Sewanee, Tennessee; and (7) a poplar site near Birmingham, Alabama. The plan will generally follow those outlined in "Standardized Working Plan for Local Tests of Seed Source," October 25, 1951; and "Working Plan for Cooperative Study of Geographic Sources of Southern Pine Seed," September 12, 1952, both prepared by the Committee on Southern Forest Tree Improvement, Subcommittee of Geographic Source of Seed.

ASSIGNMENT: Robert E. Farmer, Jr., Research Forester.

30—5. COLD REQUIREMENTS FOR BREAKING SWEETGUM DORMANCY. 211.1, 251.05. *Liquidambar styraciflua.*

OBJECT: (1) To determine the relationship between length of cold exposure and rapidity of subsequent foliation under an optimum greenhouse environment; (2) to determine whether sweetgum from the northern and southern portions of its commercial range differs in cold requirement; and (3) to determine whether periods of high temperature alternating with cold exposure will cause a reinduction of dormancy.

METHODS: In November 1964, 110 plants from each seed source were lifted from nursery beds and potted. Fifty plants from each source were placed in continuous cold storage (4°C.) and another 50 in cold storage broken by a 24-hour exposure to high temperatures every 10 days. At intervals of 20 days, 10 seedlings from each source were removed from each storage treatment and "forced" in a greenhouse. Ten seedlings from each source were "forced" immediately after potting in November. Number of days from date they are placed in the greenhouse to foliation date were observed. Data will be analyzed as for a factorial design.

ASSIGNMENT: Robert E. Farmer, Jr., Research Forester.

30—6. SEX RATIO IN NATURAL COTTONWOOD POPULATIONS. 211.2, 211.3, 251.31, 251.321. *Populus* spp.

OBJECT: Originally designed to determine cottonwood sex ratio in the lower Mississippi Valley, this test has been expanded to study phenotypic variation in cottonwood specific gravity and phenology.

METHODS: Natural stands in the Mississippi Delta region will be sampled with a nested design. Field observations will be used to determine sex ratio and dates of flowering and seed dispersal on individual trees. Specific gravity will be sampled from individual trees using large diameter increment cores.

ASSIGNMENT: Robert E. Farmer, Jr., Research Forester.

30—7. FIELD SELECTION OF SUPERIOR COTTONWOOD PHENOTYPES. 211.3. *Populus deltoides.*

OBJECT: (1) To select superior cottonwood phenotypes for use in breeding, and (2) to develop and improve selection techniques.

METHODS: Preliminary selection will include an aerial or ground reconnaissance followed by a survey of selected stands. Superior phenotypes subjectively selected in this survey will be graded using a previously developed system in which the selected tree is compared with five adjacent dominant or codominant check trees for relative growth rate, straightness, apparent pruning capability, crown forkedness, crown area, and disease and insect resistance. Final selection will be based upon phenotypic grades.

ASSIGNMENT: Robert E. Farmer, Jr., Research Forester.

30—8. FIELD SELECTION OF SUPERIOR SWEETGUM PHENOTYPES. 211.3. *Liquidambar styraciflua.*

OBJECT: Selection of phenotypically superior sweetgum from natural stands for use in a breeding program.

METHODS: Selections will be made on the basis of growth rate, straightness, pruning ability, resistance to epicormic sprouting, wood properties, and pest resistance. Seed and vegetative material will be collected for use in further breeding.

ASSIGNMENT: Robert E. Farmer, Jr., Research Forester.

30—9. TESTING AND SELECTION OF PROGENY FROM OPEN-POLLINATED COTTONWOOD MOTHER-TREES. 211.3. *Populus* spp.

OBJECT: (1) To provide a population for selection purposes; and (2) to provide information on variation and inheritance of juvenile characters important in improvement.

METHODS: Half-sib families (60 trees each) from 81 parent trees are being grown under nursery conditions in a balanced 9 x 9 lattice design. Growth parameters and Melampsora rust resistance will be measured after one and two seasons' growth. Individual tree selections will be made from the best families for clonal testing. This study is located at the Stoneville nursery.

ASSIGNMENT: Robert E. Farmer, Jr., Research Forester; James R. Wilcox, Geneticist.

30—10. A PRELIMINARY TEST OF COTTONWOOD CLONES. 211.3, 221. *Populus* spp.

OBJECT: To test early clonal performance on two sites of cottonwood selected for rapid juvenile growth in a progeny test.

METHODS: One hundred clones will be planted on two sites (Commerce loam and Sharkey clay) in triple lattice designs. Three-ramet row-plots will be used with 10 x 10 square spacing. At the end of one season's growth, clones will be evaluated on the basis of growth, wood properties, and pest resistance. Study areas are on Huntington Point, north of Greenville, Mississippi, and on the Delta Experimental Forest.

ASSIGNMENT: Robert E. Farmer, Jr., Research Forester; James R. Wilcox, Geneticist.

30—11. BROAD SENSE HERITABILITY ESTIMATES IN COTTONWOOD CLONES. 211.3, 241. *Populus deltoides.*

OBJECT: To obtain heritability estimates for several phenological and wood quality characters in cottonwood saplings and to estimate the gain from selection at various intensities. The characters of interest are: height growth, diameter growth, extent of branching, time of leaf emergence and leaf fall, specific gravity, and fiber length. Other characters will be studied if clonal differences are apparent.

METHODS: Forty-nine individual selections will be made from run-of-the-bar seedlings in a natural stand of cottonwood in the Mississippi River valley near Greenville, Mississippi. Cuttings will be planted in a randomized block design with six replications. Single tree plots will be used with 9-foot spacing between trees in both directions. Cuttings from individual selections will be assigned to replications on the basis of their relative position in the seedling stem.

ASSIGNMENT: James R. Wilcox, Geneticist; Robert E. Farmer, Jr., Research Forester.

30—12. SWEETGUM HALF-SIB PROGENY TEST. 211.3, 241. *Liquidambar styraciflua.*

OBJECT: (1) To study the variability among selected trees and their progenies; (2) to obtain estimates of heritability for selected characters; and (3) to compare performance of progenies at two locations.

METHODS: Sixty-four trees were selected to represent a range of phenotypes and sites in south Mississippi. The following measurements will be taken on the parent trees for use in the parent-progeny regression for heritability estimates: height, diameter, age, straightness, height to crown, specific gravity, and fiber length. Stratified seed from the trees will be sown in plots. After germination and establishment, the young seedlings will be transplanted to nursery beds in a triple lattice design with three replications. Spacing will be 3 inches x 3 inches with a single plot consisting of 16 seedlings. In the spring the seedlings will be transplanted to the field in a design which duplicates, at two locations, the nursery design. A field plot will consist of 8 trees from a single parent. Spacing will be 8 x 8. Height growth will be measured at the end of the nursery growing season. Field measurements to be taken over a period of a year include: survival, date of leafing out, date of full leaf, date of leaf fall, height growth, branching habit, diameter, wood specific gravity, fiber length, proportion of summerwood, extent of natural pruning, minimum flowering age, and date of flowering.

ASSIGNMENT: James R. Wilcox, Geneticist.

30—13. A LONG-TERM COTTONWOOD CLONAL TEST. 211.3, 241, 251.09. *Populus* spp.

OBJECT: (1) To test preliminary clonal selections over a short rotation period (20-30 years); (2) to compare a randomly selected clonal population with one selected on the basis of outstanding juvenile performance; (3) to obtain broad-sense heritability estimates for characters important to improve; and (4) to test the effect of two radically different sites on patterns of variation.

METHODS: Forty clones selected from preliminary tests and 40 randomly selected clones will be grown on two sites (Commerce silt loam and Sharkey clay) in randomized block designs with five replications. Four-ramet row-plots and 10 x 10 square spacing will be used. Study areas are located on Huntington Point north of Greenville, Mississippi, and on the Delta Experimental Forest.

ASSIGNMENT: Robert E. Farmer, Jr., Research Forester; James R. Wilcox, Geneticist.

30—14. A ONE-PARENT PROGENY TEST IN SWEETGUM. 211.3, 251.09. *Liquidambar styraciflua.*

OBJECT: (1) To determine patterns of variation within and between half-sib families from six geographical locations in the lower Mississippi Valley; (2) to determine the relative performance of progeny from superior and randomly selected phenotypes; and (3) to test the effect of two major site types upon patterns of variation.

METHODS: One-hundred-tree families from 81 parent trees will be grown on each of two sites (Commerce silt loam and Sharkey clay) in 9 x 9 balanced lattice designs. Growth parameter, wood properties, and pest resistance will be measured and evaluated periodically. Study areas are located on Huntington Point, north of Greenville, Mississippi, and on the Delta Experimental Forest.

ASSIGNMENT: Robert E. Farmer, Jr., Research Forester; James R. Wilcox, Geneticist.

30—15. TESTING AND SELECTION OF PROGENY FROM OPEN-POLLINATED COTTONWOOD MOTHER TREES. 212.02, 241. *Populus deltoides.*

OBJECT: (1) To provide an artificial population of cottonwood seedlings from which selections can be made; (2) to provide quantitative information on variation within and between families from open-pollinated mother trees; (3) to make an evaluation of the breeding potential of mother trees based on a nursery progeny test; and (4) to develop techniques suitable for large-scale implementation of the mother-tree approach in cottonwood breeding.

METHODS: Two hundred seedlings from each of 25 phenotypically superior female trees selected in the east batture of the Mississippi River between Clarksdale and Vicksburg, Mississippi, will be grown for 2 years under nursery conditions in 10 replications of 20 seedlings each. Seedlings will be spaced 2 feet apart in rows (3 feet apart) located randomly within replications. The following measurements will be made after 2 years' growth: (1) Total height; (2) diameter 4 inches above root collar or d.b.h., depending on average size of plants; (3) number of branches; and (4) apparent resistance to Melampsora rust. Specific gravity and fiber length determinations will also be made.

ASSIGNMENT: Robert E. Farmer, Jr., Research Forester; James R. Wilcox, Geneticist.

30—16. VEGETATIVE PROPAGATION OF HARDWOODS: ROOTING OF GREENWOOD CUTTINGS. 251.02. *Liquidambar styraciflua, Quercus* spp.

OBJECT: To develop vegetative propagation techniques for hardwoods in the tree improvement program.

METHODS: Greenwood stem cuttings from sweetgum and several oak species will be propagated under mist after various root-inducing treatments. Various experimental designs will be used.

ASSIGNMENT: Robert E. Farmer, Jr., Research Forester.

30—17. EFFECTS OF MOISTURE STRESS ON NATURAL VARIATION IN GROWTH OF COTTONWOOD CLONES. 251.07. *Populus* spp.

OBJECT: To determine the influence of moisture stress upon variation in early growth of cottonwood clones.

METHODS: Cuttings from 30 randomly selected clones will be grown in the greenhouse under two soil moisture regimes (optimum and stressful). A split-plot design with five replications will be used. After a pre-determined growth period, the following parameter will be recorded and analyzed: total height, leaf area, dry weight of roots and shoots.

ASSIGNMENT: Robert E. Farmer, Jr., Research Forester.

31. UNIVERSITY OF FLORIDA, SCHOOL OF FORESTRY

Gainesville, Florida

31—1. CYTOGENETIC STUDIES OF SOUTHERN PINE. 111.0, 111.3, 112.01. *Pinus* spp.

OBJECT: To study variation in chromosome morphology within pine species, between pine species and between pine hybrids.

METHODS: Plant tissues are collected from known and suspected pine hybrids and from representatives of the parent species. Major emphasis is placed upon meiotic divisions in immature staminate strobili. Morphological details of chromosomes are noted to determine differences between species. Meiotic irregularities are critically examined, classified as to type, and their frequency recorded. The study is part of the S-23 project.

ASSIGNMENT: R. E. Goddard, Associate Professor.

31—2. BREEDING SUPERIOR STRAINS OF SOUTHERN PINES. 111.1, 111.3, 112.02. *Pinus elliottii, P. palustris.*

OBJECT: To assess variation pattern of Southern pine species indigenous to Florida, and, with the use of data collected from genetic studies of individuals and populations, develop superior strains.

METHODS: Variation in natural populations of slash and longleaf pine is determined by observation of select and comparison trees from throughout the species range. Inherent variability in growth performance and other important characteristics and possible selection gains are studied through breeding studies involving specific crosses between individuals exhibiting various characteristics. Breeding is done both in a breeding orchard and on selected individuals in natural stands. First genetic screening of the several hundred selections will be 1-parent progeny tests conducted by the various cooperators with guidance of the University of Florida staff.

COOPERATOR: Brunswick Pulp and Paper Company; Buckeye Cellulose Corporation; Container Corporation of America; Continental Can Company; Scott Paper Company; International Paper Company; Rayonier, Incorporated; St. Regis Paper Company; Union Bag-Camp Paper Corporation.

ASSIGNMENT: R. E. Goddard, Associate Professor; R. K. Strickland, Research Associate.

31—3. NITROGEN NUTRITION AND METABOLISM IN RELATION TO PINE REPRODUCTIVE RESPONSES. 151.01, 151.03. *Pinus* spp.

OBJECT: To determine some aspects of nitrogen nutrition and metabolism in relation to pine reproduction and cone and seed development.

METHODS: Trees in a seed orchard for which past flowering records are available are selected for detailed study. Nitrogen composition of reproductive and vegetative tissues during several stages of cone development is analysed including measurement of total nitrogen and various protein fractions. By appropriate statistical techniques, the nitrogen analyses will be related to flowering and cone production. The sites and biosynthetic pathways of the utilization of nitrogen in pine reproduction will be investigated.

ASSIGNMENT: R. E. Goddard, Associate Professor; W. H. Smith, Assistant Professor.

31—4. FERTILIZATION OF SOILS FOR SOUTHERN PINES. 151.01, 151.03. *Pinus* spp.

OBJECT: To determine the growth and reproductive response of southern pine to applications of plant nutrients and to relate the response to the fertility status of principal forest soils in Florida.

METHODS: A series of replicated experiments were established in slash pine seed orchards. Treatments consisted of two or more rates of primary plant nutrients or of secondary nutrients. In areas of low pH, lime was applied in split-plots in which lime treatments make up the main plots. A factorial design was used in all experiments where practical. In most experiments, treatments have been applied annually since establishment. Height, diameter and occurrence of conelets are recorded annually. Trials were initiated in 1961 and 1962 to determine the extent of differential response of select tree progeny to major plant nutrients and other cultural treatments on flatwoods sites.

ASSIGNMENT: R. E. Goddard, Associate Professor; W. L. Pritchett, Soils Technologist; C. M. Kaufman, Professor.

31—5. EXPERIMENTAL PLOT-SIZE TRIALS FOR SOUTHERN PINE PROGENY TESTS. 153. *Pinus elliottii.*

OBJECT: To determine most adequate plot size for progeny testing southern pines.

METHODS: Slash pine seedlings from 24 geographic sources representing most of the species range were obtained in December 1959. Four separate test plantings involving these sources were established on adjacent areas employing 1-, 4-, 16-, and 36-tree plots. One hundred to 112 seedlings from each source were used in the various tests. Data from each test will be subjected to analysis of variance. Comparison of the tests will be made on basis of sensitivity in detection of source differences, and, through analysis of sequential measurements, any accentuation of differences in later measurements will be determined.

ASSIGNMENT: R. E. Goddard, Associate Professor.

31—6. EFFECTS OF TOP-PRUNING SEED ORCHARD TREES. 154.3. *Pinus taeda, P. elliottii.*

OBJECT: To determine the effect of several intensities of pruning upon development and flower production of grafted and seedling pines.

METHODS: Three degrees of pruning and a tree-bending treatment have been applied in loblolly and slash pine seed orchards and in nearby open-grown natural stands of comparable tree size. The most intensive pruning was removal of 2-years' bole growth. All treatments are replicated on several clones in both orchards. Annually, height, diameter, crown spread and flower production are tallied for all treated trees and untreated controls of each clone.

COOPERATOR: International Paper Company, Southlands Experiment Forest.

ASSIGNMENT: R. E. Goddard, Associate Professor; Roy W. Stonecypher, Silviculturist, International Paper Company.

32. UNIVERSITY OF GEORGIA, GEORGE FOSTER PEABODY SCHOOL OF FORESTRY

Athens, Georgia

32—1. PATTERN OF INHERITANCE STUDIES IN *Pinus.* 111.0, 111.3, 141. *Pinus taeda, P. elliotti, P. echinata.*

OBJECT: (1) Study the pattern of inheritance in vigor (height and diameter growth), form and disease resistance among open- and control-pollinated progeny; (2) determine the nature of parent-progeny correlations for certain characteristics of form and growth; (3) ascertain the method best suited to estimating heritability; and (4) gather native and exotic pines to be used in studies of inheritance.

METHODS: The selection of trees to provide the basic materials for the study of inherent characteristics now totals approximately 500. Some of these trees are being and will be controlled pollinated in all possible combinations. Progenies from these selected trees will be measured for short-term and long-term evaluation of growth, form and disease resistance. Heritability will be determined. Appropriate techniques are being utilized to gain a knowledge of the physical bases of inheritance of specific characteristics. The arboretum will provide germ plasm for a new gene pool which can be utilized for the creation of new trees.

COOPERATORS: College Experiment Station; Georgia Forest Research Council; Department of Botany.

ASSIGNMENT: James T. Greene, Assistant Professor; H. D. Porterfield, Forest Technician; C. L. Brown, Professor; L. W. R. Jackson, Professor; Mervin Reines, Associate Professor.

32—2. HERITABILITY STUDIES IN *Cupressus*. 111.0, 111.3, 141, 151.02. *Cupressus* spp., *Pinus* spp., *Juniperus virginiana.*

OBJECT: (1) To determine if there are differences in phenotypic expression within the genus *Cupressus;* (2) develop a control-pollination technique for the genus *Cupressus;* (3) determine if parent-progeny correlation exists for certain characters of form and growth; and (4) develop methods of vegetative propagation.

METHODS: (1) Select individual phenotypes for the following characteristics: (a) narrow crown, (b) well-formed pyramidal crown, (c) color of foliage, (d) horizontal branching, (e) stem form, and (f) those which are apparently resistant to Phomopsis blight; (2) develop methods of control-pollination and vegetative propagation; and (3) test different species of *Cupressus,* sources of Scotch pine, Japanese black pine, white pine, redcedar, and Virginia pine for possible advocation as Christmas trees.

COOPERATORS: College Experiment Station; Georgia Forest Research Council; Department of Botany; U. S. Forest Service.

ASSIGNMENT: James T. Greene, Assistant Professor; H. D. Porterfield, Forest Technician; Claud L. Brown, Professor.

32—3. SELECTION FOR EARLY STROBILI PRODUCTION. 111.3. *Pinus elliottii, P. taeda.*

OBJECT: To continually search for individuals which are producing male and female strobili at an early age, particularly slash and loblolly pine under 6 years of age.

METHODS: (1) Seedlings from open- and control-pollinations will be closely observed; (2) the young "seedlings" will be crossed with each other in all possible combinations when possible; and (3) the known parents which bear seed yielding the early "flowering" "seedlings" will also be control-pollinated and vegetatively propagated.

COOPERATORS: College Experiment Station; Georgia Forest Research Council.

ASSIGNMENT: James T. Greene, Assistant Professor; H. D. Porterfield, Forest Technician.

32—4. VARIATION AND INHERITANCE OF PHOTOSYNTHETIC EFFICIENCY AND VIGOR IN LOBLOLLY PINE. 111.3, 141. *Pinus taeda.*

OBJECT: To study and define variation and heritability of photosynthetic efficiency and its relationship to vigor.

METHODS: (1) Needles and seedlings from wind- and control-pollinated trees will be scanned with an infra-red analyzer to measure CO_2 absorption, as a measure of apparent photosynthetic activity. Seedlings will be grown under the uniform conditions of a growth chamber in sufficient numbers to permit a valid statistical analysis. Seedlings will be compared to determine variation within lots as well as between lots. Subsequently, these seedlings will be transplanted to the field to observe their growth performance. Here, a possible relationship between measured photosynthesis in young seedlings and subsequent growth may be demonstrated. (2) To start with, five trees representative of each of two vigor classes will be selected and reciprocally cross-pollinated. If more trees can be found to make up a minimum total of 10 per vigor class, we will proceed with a breeding program using bulked pollen. Resultant progeny will be tested as above in (1) and then will be outplanted in randomized blocks of six replications, 25 seedlings per plot with isolation strips provided. Annual height, diameter, and crown measurements will be made and analyzed statistically based on least squares. Inheritance of photosynthetic efficiency will be estimated using analysis of variance. The studies are part of the S-23 project.

COOPERATORS: College Agricultural Experiment Station; Georgia Forest Research Council.

ASSIGNMENT: Mervin Reines, Associate Professor.

32—5. Cytology and anatomy. 111.3, 151.32. *Pinus elliottii, P. taeda.*

OBJECT: Variation of fibril angle in wood of parents and progeny of slash pine and loblolly pine.

METHODS: (1) Determine the correlation of the fibril angle of the branch wood with that of the adjoining stem wood; (2) determine the variation in the fibril angle of first and second ring from the pith with height in the stem of the tree; (3) determine the variation in the fibril angle of the parents and their open- and cross-pollinated progeny of slash pine and loblolly pine; and (4) determine variation in fibril angle of stem wood at breast height of trees with identical age and diameter.

COOPERATORS: Georgia Forest Research Council; College Experiment Station.

ASSIGNMENT: L. W. R. Jackson, Professor; William Morse, Graduate Assistant.

32—6. The inheritance of tracheid length and specific gravity in slash and loblolly pine. 141, 151.321, 151.322. *Pinus elliottii, P. taeda.*

OBJECT: (1) To determine the effect of selection and controlled crosses and selfings as a means of altering tracheid length and specific gravity in slash and loblolly pine, and (2) to compute heritability and genetic gain estimates for the populations studied.

METHODS: (1) The first-order branches of slash and loblolly pine parents will be analyzed for tracheid length and specific gravity. (2) The first-order branches from the control-pollinated seedlings of the slash and loblolly pine parents will be analyzed for tracheid length and specific gravity. The specific gravity will be determined by the maximum moisture method. The tracheids will be measured by the use of a Micro-projector. (3) Extreme parents with tracheid length and specific gravity will be crossed, selfed, and reciprocally crossed within and between the species. (4) Control-pollinated F_1 "seedlings" which have extremes of tracheid length and specific gravity will be crossed in all possible combinations. The inclusion of the interspecific crosses as well as the shortleaf is necessary to complete the possible pattern of inheritance in tracheid length and specific gravity for the populations studied. Heritability will be determined.

COOPERATORS: College Experiment Station; Georgia Forest Research Council; University of Minnesota.

ASSIGNMENT: James T. Greene, Assistant Professor; H. D. Porterfield, Forest Technician.

32—7. Aging in trees. 151.0, 151.02. *Pinus elliottii.*

OBJECT: This project is intended to be the first in a program for the study of the chronological aging in trees. Aims are to characterize the structural and physiological bases for aging in relation to problems of vegetative propagation. The specific objective of this project is to characterize structural aging of meristematic tissues; the living cells and its contents. Such studies of cells located in tissues or regions of active cell division in the cambium and tips of stems are presumably related to the functional aspects of plant parts of aging trees and to their manifestation in propagation.

METHODS: (1) Meristematic tissues, stem tips, and cambial cells will be removed from five slash pine trees, representing each of several age classes (germinating seed, seedlings in the cotyledon stage, seedlings 1 year old, and trees 2, 5, 10, 15, and 20 years of age). From each tree in each age class five samples of stem and cambial meristems will be collected for examination. (2) These tissues will be sectioned, mounted on slides and appropriately stained for comparative studies of inter- and intracellular structure with the light microscope. (3) Living tissues of the above will be viewed with the phase microscope for comparative studies of structure and behavior. (4) Tissue culture of above materials will be made to provide suitable material for further microscopic examination and study of their relation to callus formation and consequently, vegetative propagation. (5) Appropriately prepared tissue will be examined by electron microscopy. Particular attention will be paid to the particulate structure of the cytoplasm and nucleus (mitochondria, microsomes, endoplastic reticulum, cytosomes, and nuclear inclusions) in the search for changes which might transpire with age. Particular attention will also be paid to the structural aspects of membranes and interfaces for subtle changes which may influence the transport, within the cell, of physiologically active substances.

COOPERATORS: College Experiment Station; Georgia Forest Research Council.

ASSIGNMENT: Mervin Reines, Associate Professor.

32—8. THE PROPAGATION OF NEEDLE BUNDLES. 151.02. *Pinus elliottii, P. taeda.*

OBJECT: To propagate needle bundles of loblolly and slash pines and to stimulate and sustain bud growth and development in rooted needle bundles.

METHODS: (1) One terminal branch from each of 60 young and several older trees will be collected. (2) One hundred needle bundles will be stripped from each of 50 branches. (3) They will be planted in a sand, sand-peat, or perlite medium in the sequence of their occurence on the branch. (4) Observations will be made as to rootability with relation to age or position of needles, at the end of a 6-month period. (5) Within this time interval the condition of bud primordia will be examined. (6) Needle bundles of the remaining branches will be preserved. (7) Slides will be prepared, examined microscopically to determine the condition of bud primordia at the time of planting. (8) The influence of condition of bud primordia on rooting of needle bundles and subsequent bud development will also be considered. (9) Further installations of needle bundles into propagation benches will be made to stimulate root growth and bud development by treatments with varying concentrations of urea, nucleic acids, and kinetin.

COOPERATORS: College Experiment Station; Georgia Forest Research Council.

ASSIGNMENT: Mervin Reines, Associate Professor.

32—9. *In vitro* CULTURE OF PINE CALLUS ON A DEFINED MEDIA. 151.02. *Pinus* spp.

OBJECT: (1) To determine the nutritional factors necessary for the successful growth and culture of isolated cambial cells on artificial media, and (2) to extend this information into practical ways of propagating members of the genus *Pinus.*

METHODS: Cambial explants from the four major southern pines are placed on culture media of known chemical consistency and observed for continued proliferation and callus formation. Growth factors such as auxins and kinins are introduced into the media to stimulate bud and/or root formation.

COOPERATORS: Georgia Forest Research Council.

ASSIGNMENT: Claud L. Brown, Professor.

32—10. CULTURE OF HAPLOID TISSUES *in vitro.* 151.1, 251.1. Hardwoods, softwoods.

OBJECT: (1) To grow callus cultures of female and male gametophyte tissues from gymnosperms and angiosperms *in vitro;* (2) to initiate bud and root formation on such tissues to obtain haploid plants; and (3) to double the chromosome number *in vitro* in an attempt to produce a homozygous diploid, i.e., a true breeding strain which would have much utility in practical as well as basic utilization.

COOPERATORS: Georgia Forest Research Council.

ASSIGNMENT: Claud L. Brown, Professor.

32—11. PRODUCTION OF USEFUL MUTANTS IN LOBLOLLY PINE BY IRRADIATION. 112.11. *Pinus taeda.*

OBJECT: (1) The development of more productive loblolly strains by gamma irradiation of seedlings, seed, and pollen, and (2) the determination of dosages most efficient in the production of mutants.

METHODS: One-year-old dormant and growing seedlings have been exposed to dosages ranging from 200 roentgens to 7,000r at various intensities. Surviving seedlings (200r to 1300r) are planted in randomized plots in Putnam and Spalding Counties. Other pine and hardwood species have been treated for comparison. Loblolly seed have been exposed to dosages ranging from 327r to 50,000r, along with other species. Seedlings from dosages up to 10,000r have been outplanted in replicated plots in Spalding County, for further observations. Irradiated pollen (292r to 2579r) has been applied to the flowers of selected trees, seed have been collected and planted. Seedlings from dosages through 2579r have been field planted in replicated plots in Spalding County for further tests.

COOPERATORS: Biological Laboratories, Oak Ridge National Laboratory; College of Agriculture, School of Forestry, and Agricultural Engineering Dept., Univ. of Georgia.

ASSIGNMENT: Turner S. Davis, Assistant Forester, Georgia Agricultural Experiment Station of the Univ. of Georgia.

33. UNIVERSITY OF TENNESSEE, DEPARTMENT OF FORESTRY

Knoxville, Tennessee

33—1. Pinetum. 111.0. *Pinus* species.

OBJECT: To determine which species of pine will grow in Tennessee and to compare their performance. Also, to provide a facility for production of interspecific hybrids as well as studies in cytology and taxonomy.

METHODS: A uniform area of about 100 acres has been set aside for the Pinetum. Following site preparation, the area was divided into 1-acre single species plots. To date, 26 species have been successfully established. Data on survival, growth, etc. are obtained periodically on port-a-punch.

ASSIGNMENT: Eyvind Thor, Forest Geneticist.

33—2. Pine seed source tests. 111.1. *Pinus taeda, P. echinata, P. virginiana, P. strobus, P. elliottii.*

OBJECT: To compare the performance and adaptability of planted loblolly, shortleaf, Virginia, white, and slash pine of different geographic origins to Tennessee conditions.

METHODS: Fourteen pine seed source test plantings have been established in all major physiographic regions of Tennessee, from 1955 through 1962. Tests with geographic sources of loblolly, white, slash, and shortleaf pine follow the standard pattern recommended for seed source tests. A test of 16 Virginia pine seed sources from a wide geographic range involves 24 replicates, each containing one seedling from each seed source. The Virginia pine test was enlarged in 1959 to include 20 more seed lots.

COOPERATOR: One or more of the following: Maryland Department of Natural Resources; Tennessee Valley Authority.

ASSIGNMENT: Eyvind Thor, Forest Geneticist; James S. Kring, Forester; J. T. Beavers, Forester; P. J. Huffman, Forester.

33—3. Variation in Fraser fir. 111.1, 111.3. *Abies fraseri.*

OBJECT: To determine variation between trees and seed sources for selection of trees suitable for Christmas tree production.

METHODS: Five trees were selected at each of three elevations in the Great Smoky Mountains. Cuttings were taken from three levels in the crown and of three branch orders. Cuttings from the lower level of the crown rooted best. The rooted cuttings have been outplanted for further observations on growth characteristics and possible clonal relationships. The study is part of the S-23 project.

ASSIGNMENT: Eyvind Thor, Forest Geneticist.

33—4. Wood properties. 111.1, 111.3, 151.321, 151.322, 211.1, 211.3, 251.321, 251.322. *Pinus taeda, P. strobus, P. virginiana, Liriodendron tulipifera.*

OBJECT: To study the variation between trees and between regions in specific gravity and fiber length in loblolly pine, white pine, Virginia pine, and yellow-poplar.

METHODS: Specific gravity and fiber lengths are determined from large increment cores. When provenance test plantations are available, the samples will be taken from these in order to eliminate site effect; otherwise, natural populations will be used. The studies are part of the S-23 project.

ASSIGNMENT: Eyvind Thor, Forest Geneticist.

33—5. VARIATION IN VIRGINIA PINE. 111.2, 111.3. *Pinus virginiana.*

OBJECT: To determine the variation among trees and stands for Virginia pine in Tennessee and Kentucky. Special emphasis is on wood properties.

METHODS: Fifteen trees were selected from 13 stands. A study of natural variation in wood properties has been completed. Seed has been collected from 10 trees in each stand and an open-pollinated progeny test will be made.

COOPERATOR: Society of American Foresters, Kentucky-Tennessee Section.

ASSIGNMENT: Eyvind Thor, Forest Geneticist.

33—6. VIRGINIA PINE PROGENY TEST. 111.3. *Pinus virginiana.*

OBJECT: To study the heritability of bole and crown form and other selected characters in Virginia pine.

METHODS: Progenies from trees selected for good bole and crown form were outplanted in Morgan County, Tennessee, in 1958. Periodic measurements will be taken to obtain evidence on heritability of the selected characteristics.

COOPERATOR: The Tennessee Valley Authority.

ASSIGNMENT: Eyvind Thor, Forest Geneticist; James S. Kring, Forester.

33—7. WHITE PINE SEED ORCHARD. 111.3, 122.1. *Pinus strobus.*

OBJECT: To establish and maintain an orchard with clones selected for resistance to fumes.

METHODS: Several good phenotypes with apparent resistance to fumes from a steam plant have been selected and propagated. The orchard is located near Wartburg in an area with heavy fume damage. The clones will be evaluated in the orchard and progeny tests will be made.

ASSIGNMENT: Eyvind Thor, Forest Geneticist; J. S. Kring, Forester.

33—8. PINE BREEDING ORCHARD. 112.02. *Pinus taeda, P. strobus.*

OBJECT: To establish and maintain an orchard with clones of white pines and loblolly pine. Primarily this orchard will be used for production of controlled intraspecific and interspecific crosses for later progeny tests.

METHODS: Selection and propagation of superior phenotypes for white pine are under way. Ramets of exotic white pines have also been established. Good phenotypes of loblolly pine have already been selected by other agencies, and scions from many of these trees have been propagated. Loblolly clones from most of the species range will be represented in the orchard near Knoxville, Tennesse.

ASSIGNMENT: Eyvind Thor, Forest Geneticist.

33—9. YELLOW-POPLAR SEED SOURCE TEST. 211.1. *Liriodendron tulipifera.*

OBJECT: To compare the performance of different seed sources in the different physiographic regions of Tennessee.

METHODS: Four seed sources have been outplanted in five different areas. Four replications and 25 trees per plot were used.

ASSIGNMENT: Eyvind Thor, Forest Geneticist; James S. Kring, J. T. Beavers, and P. J. Huffman, Foresters.

33—10. YELLOW-POPLAR OPEN-POLLINATED PROGENY TEST. 211.3 *Liriodendron tulipifera.*

OBJECT: To determine heritability for some important characteristics in yellow-poplar.

METHODS: Several trees in two locations, the Cumberland Mountains and West Tennessee, were examined and seed collections made. Seedlings were grown and outplanted in the two locations. Large differences are apparent after two growing seasons in the field, both among the two seed sources and among individual trees.

ASSIGNMENT: Eyvind Thor, Forest Geneticist; James S. Kring and J. T. Beavers, Foresters.

33—11. YELLOW-POPLAR BREEDING ORCHARD. 211.3. *Liriodendron tulipifera.*

OBJECT: To establish and maintain an orchard with a large number of selected yellow-poplar clones. Primarily this orchard will be used for production of controlled crosses for later progeny tests.

METHODS: Selection of outstanding yellow-poplar phenotypes has started and several clones are established. In addition to vigor, form, branches, etc., wood properties like specific gravity and fiber length are considered. The orchard is established near Knoxville, Tennessee.

ASSIGNMENT: Eyvind Thor, Forest Geneticist.

33—12. TESTING OF IMPROVED BLACK WALNUT AND CHINESE CHESTNUT. 211.3. *Juglans nigra, Castanea* spp.

OBJECT: To test improved nut trees for their adaptability to Tennessee conditions. Principal species include black walnut and Chinese chestnut.

METHODS: Testing of better varieties in plantings at several locations in Tennessee is in progress. Oldest plantings include a test of black walnut varieties at Knoxville, Tennessee, and a test of black walnut and Chinese chestnut in Hamilton County, Tennessee.

COOPERATOR: Tennessee Valley Authority.

ASSIGNMENT: Dr. B. S. Pickett, Head, Department of Horticulture; James S. Kring, Forester.

33—13. AMERICAN CHESTNUT BREEDING PROGRAM. 211.3, 212.02, 212.11. *Castanea dentata.*

OBJECT: To develop trees with resistance to blight.

METHODS: A breeding orchard has been established near Knoxville. Several trees with apparent resistance have been selected and propagation has been started. Several thousand nuts have been irradiated and the seedlings are now being outplanted for natural selection. Controlled crosses will be made with promising individuals.

ASSIGNMENT: Eyvind Thor, Forest Geneticist; Paul E. Barnett.

33—14. YELLOW-POPLAR SEED ORCHARDS. 222.1. *Liriodendron tulipifera.*

OBJECT: To establish and maintain orchards with clones selected from specific physiographic regions of Tennessee. These orchards will serve as a source of seed as well as scion wood.

METHODS: Outstanding phenotypes have been selected and several clones have been established in three orchards. East Tennessee (near Knoxville), Mountains (near Wartburg), and West Tennessee (Ames Plantation).

ASSIGNMENT: Eyvind Thor, Forest Geneticist; James S. Kring, J. T. Beavers, Foresters.

34. UNIVERSITY OF VIRGINIA
Charlottesville, Virginia

34—1. IRRADIATION OF AMERICAN CHESTNUT. 212.11. *Castanea* spp.

OBJECT: To test irradiated seeds for resistance to chestnut blight.

METHODS: Professor Singleton will arrange for collection and irradiation of seed; Virginia Division of Forestry will stratify and raise seedlings at Charlottesville Nursery and transplant them on various State lands for future evaluation as to induced resistance. First shipment irradiated nuts were received in early spring 1958 and 7,700 nuts were planted in nursery. Because of high rate of irradiation, only 73 irradiated seedlings survived to be outplanted at the Cumberland State Forest (with some untreated checks) in early March 1959. In the same area were 24 seedlings provided by Dr. Albert Dietz and planted November 1958. Only 4 percent survived when checked in spring 1961. One hundred and seventy-five pounds of seed received January and February 1959 were stratified and planted March 20, 1959, (estimated 14,600 nuts planted Charlottesville Nursery). Yield by spring of 1960 was 1,200 seedlings which were transplanted to a field at Charlottesville Nursery. Only 1 percent were surviving by fall 1962, the remainder having succumbed mainly to root rot.

COOPERATOR: Virginia Division of Forestry.

ASSIGNMENT: C. L. Morris, Forester.

35. VIRGINIA DIVISION OF FORESTRY
Charlottesville, Virginia

35—1. Loblolly, white, and shortleaf pine seed production areas and seed orchards. 122.0, 122.1. *Pinus taeda, P. echinata, P. strobus.*

OBJECT: To produce improved seed for use in the tree nurseries and direct seeding.

METHODS: An intensive search for loblolly, shortleaf, and white pine super trees has been completed. For loblolly pine, both Piedmont and coastal plain seed orchards of 70 acres, will be established. For shortleaf, it is planned to have only a single Piedmont seed orchard of 10 acres. A 40-acre white pine seed orchard is planned. About 86 acres of loblolly pine and 61 acres of shortleaf pine seed production areas have been established. Progeny testing is planned.

ASSIGNMENT: R. L. Marler, Forester.

36. WEST VIRGINIA PULP AND PAPER COMPANY
Summerville, South Carolina

36—1. Open-pollinated progeny test of superior loblolly pine and pond pine seedlings. 111.3. *Pinus taeda, P. serotina.*

OBJECT: To progeny test open-pollinated seedlings from superior trees selected on deep peat (1-10 feet) sites in eastern North Carolina.

METHODS: Open-pollinated seedlings produced from 16 superior pond pine and 15 superior loblolly pine were field planted on a deep peat (6 feet plus) site beginning in 1960. Final field planting will be in 1966. Plots consist of 25 seedlings from each superior tree and the five best check trees. Each plot is replicated four times in a randomized design.

ASSIGNMENT: J. L. Landino, Project Leader.

36—2. Control-pollinated progeny test of superior loblolly pine and pond pine seedlings. 111.3. *Pinus taeda, P. serotina.*

OBJECT: To progeny test control-pollinated seedlings from superior trees selected on deep peat (1-10 feet) sites in eastern North Carolina.

METHODS: Control-pollinated seedlings produced by crossing 16 superior pond pine and 15 superior loblolly pine trees, using 4 pollen testers for each species, will be field planted beginning in 1966. Control-pollinations are well under way, but of the necessary crosses only 30 percent of the pond pine and 10 percent of the loblolly pine have been completed. Plot design will be as recommended by the North Carolina State-Industry Tree Improvement Program under the direction of Dr. B. J. Zobel. Seedlings will be planted on a deep peat site.

COOPERATOR: Dr. B. J. Zobel.

ASSIGNMENT: J. L. Landino, Project Leader.

36—3. Controlled-pollination progeny test of seed orchard selections. 111.3, 112.02. *Pinus taeda.*

OBJECT: (1) To determine superiority of clones used in seed orchard; (2) to determine combining ability of the clones; and (3) to further determine what characteristics are genetically controlled.

METHODS: Pollen from 14 ortets selected for the seed orchard was applied separately to flowers of another ortet in 1958. Ten seedlings of each cross were outplanted in an old field in 1961. Tree used as the common tester is located at Westvaco Experimental Forest, Georgetown, South Carolina. Pollen parents are located throughout the South Carolina coastal plain.

ASSIGNMENT: D. M. Crutchfield, Project Leader.

36—4. Open-pollinated progeny tests of seed orchard selections. 111.3, 112.02. *Pinus taeda.*

OBJECT: To determine whether progeny of ortets selected for seed orchard are superior in the qualities desired; to determine what characteristics are genetically controlled.

METHODS: Plots of open-pollinated progeny, containing 25 seedlings each, are planted adjacent to plots of progeny from trees in same stand as the ortet. Tests of eight ortets established in 1959, replicated four times in one location, once on another site. Seven more ortets were tested in 1960, six additional ortets in 1965. Plantings located on old field and flatwoods sites at Westvaco Experimental Forest.

COOPERATOR: North Carolina State University, School of Forestry.

ASSIGNMENT: D. M. Crutchfield, Project Leader.

36—5. Tests of Pine hybrids. 112.01. *Pinus serotina, P. taeda, P. palustris, P. elliottii.*

OBJECT: A group of informal studies to determine inheritance of such qualities as growth rate, bole and crown form, branching habits, and adaptability to various sites.

METHODS: The following hybrids have been planted:

Pond pine × loblolly	60 seedlings planted 8 x 8
Longleaf × loblolly	35 seedlings planted 8 x 8
Longleaf × slash	23 seedlings planted 8 x 8
Loblolly × slash	7 seedlings planted (row)
Loblolly × loblolly	80 seedlings planted 8 x 8
loblolly × loblolly (open pollinated)	60 seedlings planted 8 x 8
(Shortleaf × loblolly) × loblolly	60 seedlings planted 8 x 8
Shortleaf × slash	Seedlings to be raised 1965 and outplanted 1966

ASSIGNMENT: D. M. Crutchfield, Project Leader.

36—6. Pollination of superior pitch pine with loblolly pollen. 112.01. *Pinus rigida, P. taeda.*

OBJECT: To produce species hybrids from select parent trees.

METHODS: Over 2,000 grafts were made from 30 loblolly and 28 pitch pine select trees between March 24 and April 30, 1965, at Charlottesville, Virginia. All of the loblolly and the majority of the pitch pine parents were selected by personnel of Northeastern Forest Experiment Station, New Lisbon, New Jersey, Research Center. The Hancock and Charlottesville Research Centers of West Virginia Pulp and Paper Company selected 12 pitch pines.

COOPERATOR: Northeastern Forest Experiment Station, U. S. Forest Service.

ASSIGNMENT: David W. Sowers, Jr., Research Center Leader.

36—7. Slash x pond pine hybridization. 112.01. *Pinus elliottii, P. serotina.*

OBJECT: Develop superior hybrid for planting on difficult organic soil sites.

METHODS: Pistillate flowers of superior slash pine growing in Union Bag-Camp's orchard were crossed with pond pine pollen from superior trees selected on deep organic soil sites. Union Bag-Camp has successfully completed the cross started in 1962. The reciprocal of this cross has not been successful to date.

COOPERATOR: Union Bag-Camp Paper Corporation.

ASSIGNMENT: J. L. Landino, Project Leader.

36—8. Experimental seed orchards of loblolly pine and pond pine. 122.1. *Pinus serotina, P. taeda.*

OBJECT: To produce superior seed for regenerating deep organic soil sites in eastern North Carolina.

METHODS: Grafts from 16 superior pond pines and 15 superior loblolly pines are included in the orchard. The orchard was started in 1957 and consists of approximately 25 acres of each species. The superior trees were all selected on deep peat (1-10 feet) sites.

ASSIGNMENT: J. L. Landino, Project Leader.

36—9. ROOTING POND PINE CUTTINGS TAKEN FROM MATURE TREES. 151.02. *Pinus serotina.*

OBJECT: To learn how to root cuttings taken from grafted superior trees to overcome incompatibility or for developing and expanding a seed orchard.

METHODS: Cuttings (6-8 inches long) taken from grafted superior trees in December were placed in a heated rooting bed. The bed consists of 3 inches of peat covered by 3 inches of vermiculite. The entire bed is enclosed in a plastic-covered Wardian case and heated by regular greenhouse heating cables. Temperature in the rooting medium varies between 75° and 85° F. The study was started in December 1963 and 8 percent of the 60 cuttings rooted and were field planted 104 days after being placed in the rooting bed. The study was repeated in December 1964.

ASSIGNMENT: J. L. Landino, Project Leader.

36—10. YELLOW-POPLAR PROVENANCE STUDY. 211.1. *Liriodendron tulipifera.*

OBJECT: To determine racial variation in yellow-poplar.

METHODS: Four seedlings each of 12 provenances of yellow-poplar were supplied by the University of Maryland and were part of a large study. The plantings are in two blocks with two replicates of four seedlings each in each block. The plots are arranged in a Latin square. Plots were established April 2, 1963, on the Robert Eddy tract of West Virginia Pulp and Paper Company on the Cairo-Cisco road, Ritchie County, West Virginia. Elevation is 800 feet, aspect N 75 E, slope 15 percent. Area supports a stand of dwarf sumac, and the poplars were planted under the sumac. Soil is Meigs, heavy-textured, and well drained from interbedded alkaline and acid shales.

COOPERATOR: Professor John Genys, Natural Resources Institute, University of Maryland.

ASSIGNMENT: David W. Sowers, Jr., Research Center Leader.

A TABULAR SUMMARY

Summaries of the information contained in the project statements are given in five tables. The tables are intended to show the amount and type of work under way with forest tree genera and certain tree species as well as the number of projects or studies. This treatment is necessary because certain projects may involve several species as well as a number of different subjects. Although the tables were not designed to summarize all the information given in the project descriptions, they do indicate the relative amount of research effort devoted to various forest trees and research subjects. The tables do not cross-check because of the combination of factors covered.

Table 1.—*Projects by research agencies and genera*

Genera	Research agencies (code numbers are shown page iii)																																				Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
Abies																																	1				1
Acer											2																										2
Betula											1																										1
Castanea											1																		1				2	1			5
Casuarina						1																															1
Cupressus	3																		1													1					5
Eucalyptus						3																															3
Fraxinus			1	1						1																											3
Grevillea						1																															1
Juglans											1																						1				2
Juniperus			2								2							1	2													1					8
Liquidambar	3		1	1						4							2		1				1					8		5							26
Liriodendron			1							4	1					2	1		1									1		1			5			1	18
Nyssa			1							1								1	1																		4
Pinus	5	1	6	9	2		1	4	1	8	2	10	8		1	3	4	5	8	3	2	1	13	5	27	7	16	44	3		6	10	7		1	9	232
Platanus				1					1	1							1																				4
Populus											1								1									1		11							14
Prunus											1					1																					2
Quercus			1							1	1					3			1											1							8
Tsuga																1																					1
General	1				1					3	2			1		1	1							1	1		1	1				1					15
Total	12	1	13	12	3	5	1	4	2	23	15	10	8	1	1	11	9	7	16	3	2	1	14	6	28	7	17	55	4	18	6	13	16	1	1	10	356

Table 2—*Projects by categories and genera (softwoods)*

	Subject-matter classification	*Abies*	*Cupressus*	*Juniperus*	*Pinus*	*Tsuga*	General	Total
11	Selection and testing of variation				1			1
111	Natural variation				6			6
111.0	Natural variation among species		3	3	72		6	84
111.1	Natural variation among races	1	1	3	86	1		92
111.2	Natural variation among stands				7			7
111.3	Natural variation among individuals	1	2	2	109			114
112.01	Interspecific hybridization				57			57
112.02	Intraspecific hybridization				42			42
112.03	Selfing				5			5
112.11	Mutation by physical treatment				7			7
112.12	Mutation by chemical treatment				1			1
122.0	Seed production areas				11			11
122.1	Seed orchards		1		21			22
122.2	Registered seed				2			2
13	Genetics in silviculture				3			3
14	Fundamental genetics studies				4			4
141	Mode of inheritance		1	1	43		2	47
144	Evolution				1			1
151.0	Physiology				17			17
151.01	Flower induction				6			6
151.02	Vegetative propagation		2	1	12			15
151.03	Nutritional studies				9			9
151.07	Drought resistance				1			1
151.08	Phenology				1			1
151.09	Soil effects				4			4
151.1	Cytology				1		1	2
151.3	Morphology and anatomy			1	4			5
151.32	Wood characteristics				20		1	21
151.321	Wood density				8			8
151.322	Fiber length				6			6
151.5	Pathology				10			10
152.0	Entomology				10			10
153	Biometry				12		1	13
154	Special techniques				2			2
154.0	Controlled pollination				3			3
154.3	Seed orchard tree shaping				4			4
154.4	Seed orchard spacing				1			1
154.5	Pollen flight				1			1
	Total	2	10	11	610	1	11	645

Table 3.—*Projects by categories and genera (hardwoods)*

	Subject-matter classification	*Acer*	*Betula*	*Castanea*	*Casuarina*	*Eucalyptus*	*Fraxinus*	*Grevillea*	*Juglans*	*Liquidambar*	*Liriodendron*	*Nyssa*	*Platanus*	*Populus*	*Prunus*	*Quercus*	General	Total
211	Natural variation									2	1	1				1	1	6
211.0	Natural variation among species	1	1	1	1	2	1	1	1	3	3	1	1	4	1	2	4	28
211.1	Natural variation among races	1			1	2		1		4	6	1				2		18
211.2	Natural variation among stands									1				1				2
211.3	Natural variation among individuals	1	1	3		1	1		2	7	6		3	11	2	4	1	43
212.01	Interspecific hybridization			1														1
212.02	Intraspecific hybridization			1			1			1			1	2				6
212.11	Mutation by physical treatment			2														2
221	Clonal lines													1				1
222.1	Seed orchard										1							1
241	Mode of inheritance									3	2	1		4		1	3	13
251.02	Vegetative propagation						1			4	2		1			1	1	10
251.05	Thermoperiodism									1								1
251.07	Drought resistance													1				1
251.09	Soil effects					1				2				1				4
251.1	Cytology									1	1						1	3
251.3	Morphology and anatomy						1			1	1	1						4
251.31	Flower primordia													1				1
251.32	Wood characteristics						1			1	1	1	1			1	1	7
251.321	Wood density										1			1				2
251.322	Fiber length										1							1
251.5	Pathology															1		1
252.0	Entomology													1				1
253	Biometry																1	1
254.0	Controlled pollination									4	1							5
	Total	3	2	8	2	6	6	2	3	35	27	6	7	28	3	13	13	164

Table 4.—Pinus *projects by research agencies and species*

	Agencies conducting research	*clausa*	*echinata*	*elliottii*	*elliottii* var. *densa*	*glabra*	*palustris*	*rigida*	*serotina*	*x sondereggeri*	*strobus*	*taeda*	*virginiana*	Genus[1]	Total
1	Auburn University		1	1			1					2	3	1	9
2	Buckeye Cellulose Corporation			1											1
3	Clemson University		1	1			1					3	2		8
4	Continental Can Company			7			3					7	1	2	20
5	Florida Forest Service	1		2	1		1								5
7	Ida Cason Callaway Foundation		1	2			1					2			6
8	International Paper Company			1										3	4
9	Louisiana State University											1			1
10	North Carolina State University			1					1		1	2	1	7	13
11	Tennessee Valley Authority		1								2	2	2	1	8
12	Texas Forest Service			2								10			12
13	Union Bag-Camp Paper Corporation	1		6		1	1	1	1				1	2	14
14	U.S.F.S., Forest Products Laboratory													1	1
15	U.S.F.S., Region 8													1	1
	U.S.F.S., Southeastern Forest Experiment Station														
16	Asheville, North Carolina										2			1	3
17	Athens, Georgia		2							1				1	4
18	Blacksburg, Virginia		3								1	2	3		9
19	Charleston, South Carolina	1	1	2		1	5		1			4		1	16
20	Cordele, Georgia			3											3
21	Fort Myers, Florida			1	2		1					1			5
22	Franklin, Virginia											1			1
23	Macon, Georgia		2	6			1			1		8		3	21
24	Marianna, Florida	4	2	3			2					3	1		15
25	Olustee, Florida	1		26			4			1		2		1	35
	U.S.F.S., Southern Forest Experiment Station														
26	Alexandria, Louisiana		3	5			6					3		1	18
27	Crossett, Arkansas		4			1				1		15		1	22
28	Gulfport, Mississippi		11	22			13	1		3		12		7	69
29	Harrison, Arkansas		1									2			3
31	University of Florida			3			1					1		3	8
32	University of Georgia		1	6								7		2	16
33	University of Tennessee		1	1							4	3	4	1	14
35	Virginia Division of Forestry		1								1	1			3
36	West Virginia Pulp and Paper Corp.			2			1	1	6			7			17
	Total	8	36	104	3	3	42	3	9	7	11	101	18	40	385

[1] Apply to several pine species.

Table 5.—Pinus *projects by subject categories and species*

	Subject-matter classification	*clausa*	*echinata*	*elliottii*	*elliottii* var. *densa*	*glabra*	*palustris*	*rigida*	*serotina*	*x sondereggeri*	*strobus*	*taeda*	*virginiana*	Genus	Total
11	Selection and testing of variation													1	1
111	Natural variation			1					1		1	2		1	6
111.0	Natural variation among species	3	7	12	1	2	10		1	2	2	16	4	12	72
111.1	Natural variation among races	2	14	23	1	1	9	1		1	4	23	6	1	86
111.2	Natural variation among stands			1			1					3	2		7
111.3	Natural variation among individuals		10	30			9		2	2	4	37	7	8	109
112.01	Interspecific hybridization	1	9	13		1	8	3	3	3		7	1	8	57
112.02	Intraspecific hybridization		5	16			6				1	9		5	42
112.03	Selfing		1	3									1		5
112.11	Mutation by physical treatment		1	1								5			7
112.12	Mutation by chemical treatment											1			1
122.0	Seed production areas		1	4							1	3		2	11
122.1	Seed orchards	1	2	4	1		2		1		2	5	1	2	21
122.2	Registered seed			1								1			2
13	Genetics in silviculture			3											3
14	Fundamental genetics studies		1	1			1					1			4
141	Mode of inheritance		1	16			5		1	2	1	10	1	6	43
144	Evolution													1	1
151.0	Physiology		3	7			2					3	1	1	17
151.01	Flower induction			3								1		2	6
151.02	Vegetative propagation			4					1			3	1	3	12
151.03	Nutritional studies			5								1		3	9
151.07	Drought resistance											1			1
151.08	Phenology			1											1
151.09	Soil effects	1		1			1					1			4
151.1	Cytology													1	1
151.3	Morphology and anatomy		1	1			1					1			4
151.32	Wood characteristics		1	6			3		1		1	7		1	20
151.321	Wood density			2							1	4	1		8
151.322	Fiber length			1							1	3	1		6
151.5	Pathology		2	4			1					1		2	10
152.0	Entomology	1	2	1			1					2		3	10
153	Biometry		2	3			2					2		3	12
154	Special techniques			1								1			2
154.0	Controlled pollination			1			1					1			3
154.3	Seed orchard tree shaping			2								2			4
154.4	Seed orchard spacing			1											1
154.5	Pollen flight													1	1
	Total	9	63	173	3	4	63	4	11	10	19	157	27	67	620

A GENERAL SUMMARY

The information given in the tables can be summarized as follows to give an over-all view of forest tree improvement and forest genetics research in the South and Southeast:

1. Some 36 agencies, or combinations of agency and geographic location, such as various field projects of the Forest Experiment Stations, are conducting 305 projects or studies involving 20 forest tree genera and 39 research subjects. A few projects characterized by general subject matter are reported (page 3 and tables 1, 2, and 3).
2. Of the 305 projects or studies reported, 186, or 61 percent, are being conducted by the two U. S. Forest Service Forest Experiment Stations; 61, or 20 percent, by education institutions usually in connection with State Agricultural Experiment Stations; and 58, or 19 percent, largely by industry but including some by state forestry agencies, the Tennessee Valley Authority, and other Federal agencies (page 3 and table 4).
3. The 305 separate projects reported often include work on more than one genera, so that there are 356 combinations of investigations by research agency and genera (table 1). The 356 investigations include 232, or 65 percent, with the genus *Pinus;* 14, or 4 percent, with other softwood genera; and 110, or 31 percent, with some 15 hardwood genera or with forest trees in general (page 3 and table 1).
4. Studies concerned with natural variation and variation among species, races, and individual trees are by far the most numerous. In softwoods these three subjects account for 47 percent of the research effort. In hardwood they account for 57 percent (tables 2 and 3).
5. Studies concerned with induced variation by hybridization among and within species, selfing, and creation of mutations receive 17 percent of the research effort in softwoods and 6 percent in hardwoods (tables 2 and 3).
6. Utilization of selected variants for planting by production of clonal lines or by seed from seed production areas or seed orchards and the application of genetics in silviculture receive 6 percent of the research effort in softwoods and about 1 percent in hardwoods (tables 2 and 3). However, as was stated in the section on the pattern of project descriptions, no effort has been made to include all seed production areas and seed orchards in the survey.
7. Fundamental genetic studies receive about 8 percent of the research effort each in the softwoods and hardwoods (tables 2 and 3).
8. Supporting sciences in physiology, cytology, taxonomy, morphology and anatomy, ecology, pathology, entomology, and biometry, plus work on special techniques related to pollination methods or seed orchard culture account for 22 percent of the research effort in softwoods and 28 percent in hardwoods (tables 2 and 3).
9. The 356 investigations reported include 26, or 8 percent, concerned with sweetgum and 18, or 5 percent, with yellow-poplar. The work with these two species is about 46 percent of the total research effort on hardwood genera or trees in general (table 1).
10. Of the 385 *Pinus* investigations reported by agency and tree species; 36, or 9 percent, involve shortleaf pine; 104, or 27 percent, slash pine; 42, or 9 percent, longleaf pine; 101, or 26 percent, loblolly pine; and 129, or about 29 percent, the 8 other pine species, one variety, one natural hybrid, and *Pinus* in general (table 4).
11. A total of 620 investigations are in progress (table 5).

SUBJECT-MATTER CLASSIFICATION

TREE IMPROVEMENT RESEARCH PROJECTS

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11	A. Selection and testing of variation
111	1. Natural variation
111.0	a. Among species
111.1	b. ” races (ecotypes)
111.2	c. ” stands
111.3	d. ” individuals
112	2. Induced variation
112.0	a. By recombination
112.01	(1) Interspecific hybridization
112.02	(2) Intraspecific hybridization
112.03	(3) Selfing
112.1	b. By mutation
112.11	(1) Physical treatments (radiation, etc.)
112.12	(2) Chemical treatments (colchicine, etc.)
12	B. Utilization of selected variants for planting by production of
121	1. Clonal lines
122	2. Seed
122.0	a. Seed production areas
122.1	b. Seed orchards
122.2	c. Registered seed
13	C. Applications of genetics in silviculture and management of naturally reproduced stands
14	D. Fundamental genetic studies
141	1. Mode of inheritance
142	2. Reaction range
143	3. Experimental taxonomy
144	4. Evolution
15	E. Supporting sciences and special techniques
151	1. Botany
151.0	a. Physiology
151.01	(1) Flower induction
151.02	(2) Vegetative propagation
151.03	(3) Nutritional studies
151.04	(4) Photoperiodism
151.05	(5) Thermoperiodism
151.06	(6) Chemistry
151.07	(7) Drought resistance
151.08	(8) Phenology
151.09	(9) Soil effects
151.1	b. Cytology
151.11	(1) Chromosome numbers
151.2	c. Taxonomy
151.3	d. Morphology and anatomy
151.31	(1) Flower primordia
151.32	(2) Wood characteristics
151.321	(a) Density
151.322	(b) Fiber length
151.323	(c) Fibril angle
151.324	(d) Heartwood, sapwood
151.325	(e) Compression wood
151.326	(f) Tension wood
151.331	(1) Agamospermy
151.332	(1) Vegetative reproduction
151.34	(1) Leaves
151.4	e. Ecology
151.5	f. Pathology
152	2. Zoology
152.0	a. Entomology
153	3. Biometry
154	4. Special techniques
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154.01	(1) Pollen collection
154.02	(2) Pollen storage
154.03	(3) Bagging
154.04	(4) Methods
154.1	b. Climbing gear
154.2	c. Nursery techniques
154.3	d. Seed orchard tree shaping
154.4	e. Seed orchard spacing
154.5	f. Pollen flight
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Summer Planting of Slash Pine Shows Promise in Florida

by

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Southeastern Forest Experiment Station - Asheville - North Carolina
U.S. Department of Agriculture - Forest Service

Summer Planting of Slash Pine Shows Promise in Florida

by

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In the summer of 1916, Wilbur Mattoon dug 50 slash pine seedlings from the edge of a slash-cypress pond in north Florida, and shipped them parcel post to the Clemson Coastland Experiment Station in South Carolina. They were outplanted upon arrival. Astonishingly, half of the seedlings survived to become the first slash pine plantation in the United States. Mattoon concluded that "young slash pine possessed unusual vigor, and therefore was well adapted for planting."[1]

No one seems to have concluded from Mattoon's results that summer planting might be practical. Perhaps his contemporaries were influenced by Pearson's work in the Southwest, which indicated that coniferous seedlings planted in the summer suffered more shock than those planted in the dormant season.[2] Very likely, most tree planters then and later accepted cool-season planting without question, and would have rejected immediately any thoughts of planting bare-rooted, succulent seedlings under a hot summer sun. Whatever the reasons, the millions of slash pine seedlings that have been produced in southern nurseries since 1916 have been outplanted in fall, winter, or spring.

In 1958, McGregor took a fresh look at the pine planting program in northeastern Florida in relation to the climate. This area receives more than 50 inches of rain annually, but half of it falls between early June and late September, leaving the rest of the year relatively dry. The optimum planting season is generally considered to be from December to March. Seedlings planted before December are often killed by fall drought, while those planted after February may die during the dry, windy spring. Disregarding the entrenched ideas on tree planting, McGregor planted slash pines for three summers, beginning in 1958. These seedlings, which were 4 to 5 months old when planted, survived and grew as well as or better than 1-0 stock planted the following winters.[3]

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[1] Mattoon, W. R. Twenty years of slash pine. J. Forest. 34: 562-570. 1936.

[2] Pearson, G. A. Forest planting in Arizona and New Mexico. Soc. Amer. Forest. Proc. 9(4): 457-478. 1914.

[3] McGregor, W. H. D. Successful summer planting of slash pine. J. Forest. 63: 208-209. 1965.

To evaluate summer planting on different sites and under production-type operations, the Southeastern Forest Experiment Station began further studies in northeastern Florida in 1963 and 1964.[4] Results were so encouraging that various companies and government agencies agreed to plant one million slash pine seedlings in Florida and south Georgia in the summer of 1966. If these plantings succeed, summer planting can probably be considered as reliable as winter planting in this region, and guidelines for summer planting can be published. As an interim guide, this paper presents results and tentative conclusions from the 1963 and 1964 studies.

NURSERY METHODS

Planting stock was produced at two Florida Forest Service nurseries in north Florida. In 1963, seed was sown in mid-April for August-through-December plantings. In 1964, seed was sown in the nursery in early March for July-through-October outplantings, and nursery sown in mid-April for November and January field plantings.

Three storage treatments were tested in 1963: (a) 3 days under refrigeration, baled; (b) 3 days without refrigeration, baled; and (c) no storage, in which seedlings were lifted, baled, and outplanted within 2 to 4 hours. The no-storage treatment was omitted from the 1964 studies.

OUTPLANTING

The field planting plots were installed in replicated, completely randomized designs. Seedlings were transported to the field in an open truck, arrived at the planting sites in midmorning, and were planted by noon.

In 1963, seedlings were planted on a poorly drained Leon fine sand on the Olustee Experimental Forest in Baker County, Florida. Three-inch deep furrows were plowed one week before each planting date. Seedlings were planted down the furrow centers.

In 1964, seedlings were planted on the same poorly drained site. Several weeks before the first planting date, ridges were constructed with a fireplow on 8-foot centers and packed into 1-foot-high beds with a crawler tractor. Seedlings were planted on the beds, and in the furrows between the beds.

Also in 1964, seedlings were planted by the Florida State Armory Board on the Camp Blanding Military Reservation in Clay County, Florida. An excessively drained Lakeland sand was chosen for the planting site in order to determine the response of summer-planted seedlings not in contact with a water table. A light cover of young scrub oak and sand pine was disk harrowed, and then final site preparation and planting were accomplished with a fireplow and planting machine drawn in tandem. Seedlings were planted in strips scalped 1 to 2 inches deep and in furrows 5 inches deep.

---

[4] In 1965, production-type summer planting trials were initiated by the Florida State Armory Board and by Hudson Pulp and Paper Corporation in northeastern Florida, by the Florida Forest Service in central Florida, and by Lykes Brothers, Inc., in south Florida.

RESULTS AND DISCUSSION

Survival

Survival of summer plantings generally has been good, although not the equal of that in winter plantings (table 1). The only failures were the August 15, 1963 planting (probably due to loose planting in furrows flooded by heavy rains) and that of July 9, 1964 (caused by shallow planting with an incorrectly adjusted planting machine).

Survival of the October and early November plantings was high. However, planting during these months can be risky because of prolonged fall droughts that occur almost every year.

Table 1.--Survival of slash pine seedlings 1 year after planting in summer, fall, and winter

Date of planting	Poorly drained site		Excessively drained site	
	Furrows	Beds	Scalped strips	Furrows
	Percent survival			
Summer 1963				
Aug. 1	82	--	--	--
Aug. 15	8	--	--	--
Aug. 29	74	--	--	--
Sept. 12	88	--	--	--
Sept. 26	78	--	--	--
Summer 1964				
July 2	64	88	--	--
July 9	--	--	29	41
Aug. 6	70	90	--	--
Aug. 13	--	--	78	89
Sept. 3	56	84	--	--
Sept. 16	--	--	80	87
Fall 1963				
Oct. 10	85	--	--	--
Fall 1964				
Oct. 2	97	86	--	--
Oct. 8	--	--	86	92
Nov. 5	98	98	--	--
Winter 1963				
Dec. 12	97	--	--	--
Winter 1964-65				
Jan. 15	98	99	--	--
Jan. 21	--	--	88	94

Lifting and planting on the same day had only a slight beneficial effect on seedling survival. In most plantings, refrigerated storage resulted in higher survival than nonrefrigeration, but in some plantings this effect was reversed. Full understanding of the effects of refrigeration will require further study. Because of the small differences among storage treatments, survival data for these treatments were averaged for presentation in table 1.

On the poorly drained site, water stood in furrows for several days following heavy rains, and survival was higher on the beds. On the excessively drained site, survival was higher in furrows than in scalped strips.

In order to minimize weed competition, most plots were site prepared just before planting. This precaution probably was unnecessary. In more recent summer planting studies, early survival is high among seedlings planted as long as 1 year after site preparation.

Growth

At the end of the first full growing season in the field, winter plantings averaged 10 to 12 inches tall, and summer and fall plantings averaged 7 to 15 inches tall. Generally, heights increased from the earliest summer planting to a peak in a fall planting, then decreased toward the winter planting (figures 1 and 2). As in McGregor's studies, summer and fall plantings ceased height growth after outplanting, then generally grew faster the following year than did the winter plantings.

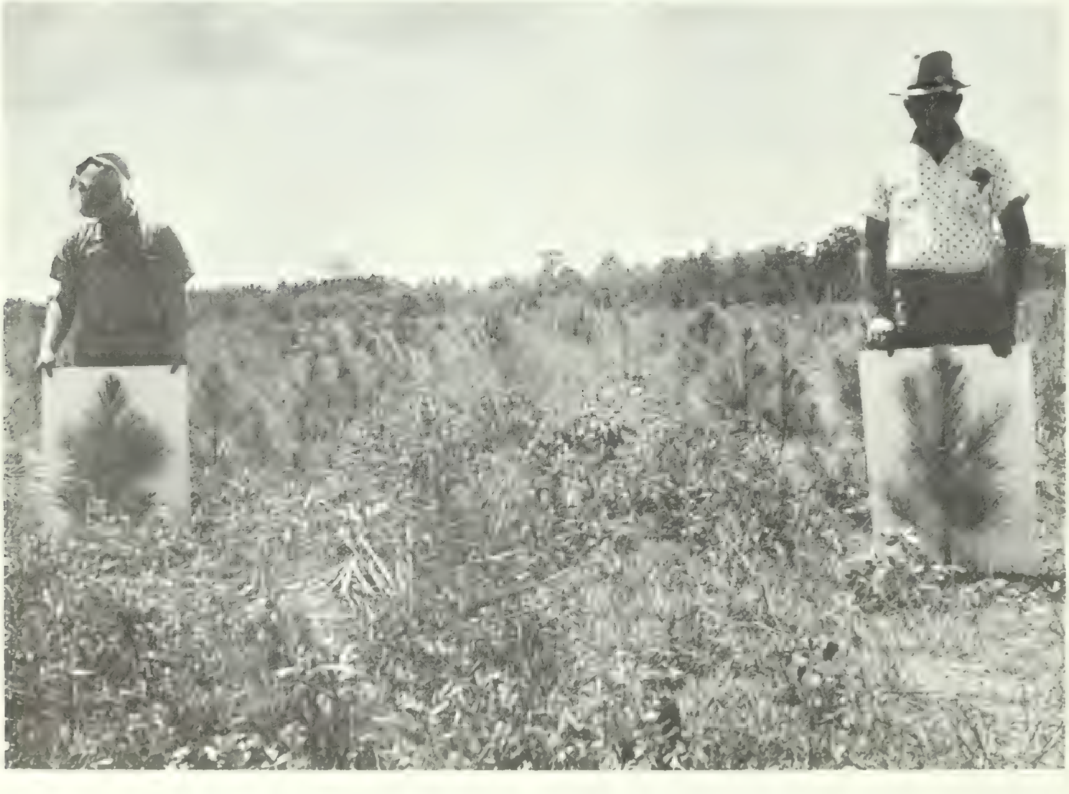


Figure 1.--After 2 years on an excessively drained site, slash pine seedlings planted in August (right) are as tall as stock planted the following January (left).

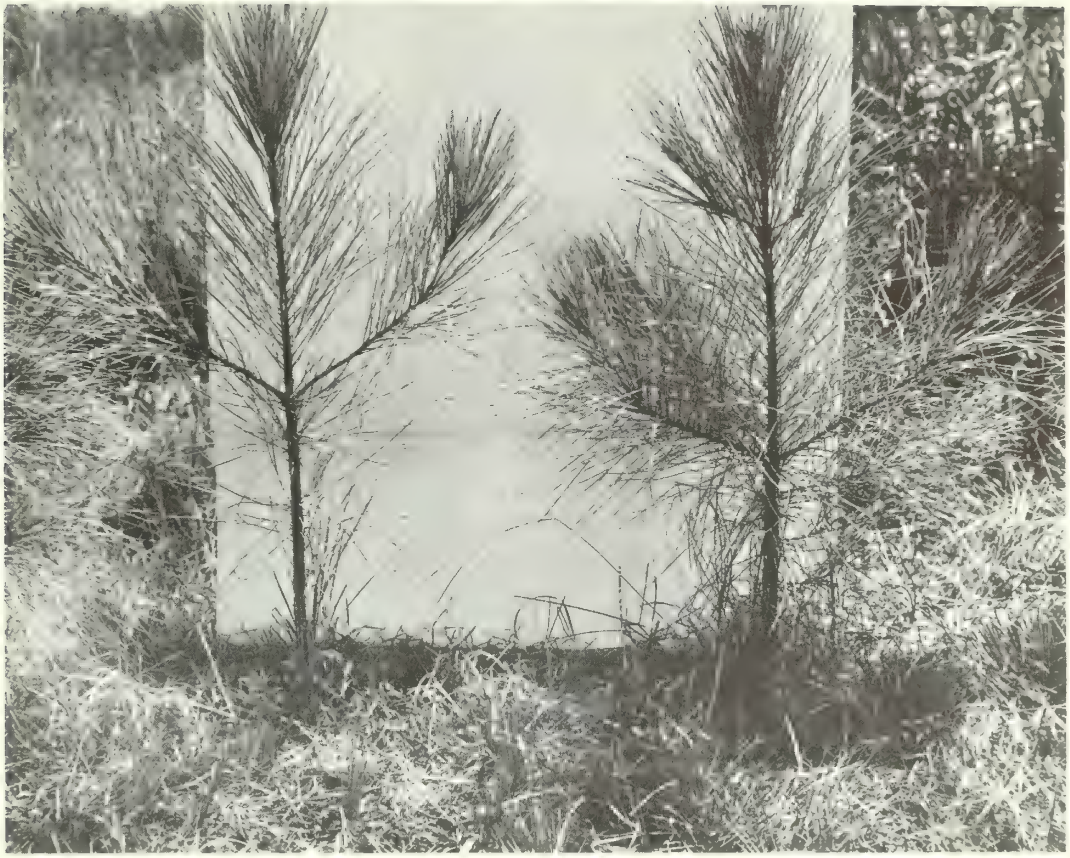


Figure 2.--After 2 years on a poorly drained site, slash pine seedlings planted in July (left) are as tall as stock planted the following January (right).

Whether seedlings were refrigerated in storage, not refrigerated in storage, or planted immediately made no difference to growth. On the excessively drained site, seedlings grew at the same rate in furrows as in scalped strips (fig. 3). On the poorly drained site, seedlings averaged 3 inches taller on beds than in furrows (fig. 4).

CONDITION OF PLANTING STOCK

In both summers, the earliest lifted seedlings were of acceptable planting height, but in comparison with winter-lifted seedlings were light in weight and high in shoot-root ratios:

Planting date	Average height	Ovendry weight	Shoot-root ratio
	(Inches)	(Grams)	
Aug. 1, 1963	8.3	1.1	6/1
Dec. 12, 1963	10.7	3.1	4/1
July 2, 1964	6.1	0.7	5/1
Jan. 21, 1965	8.7	2.6	3/1

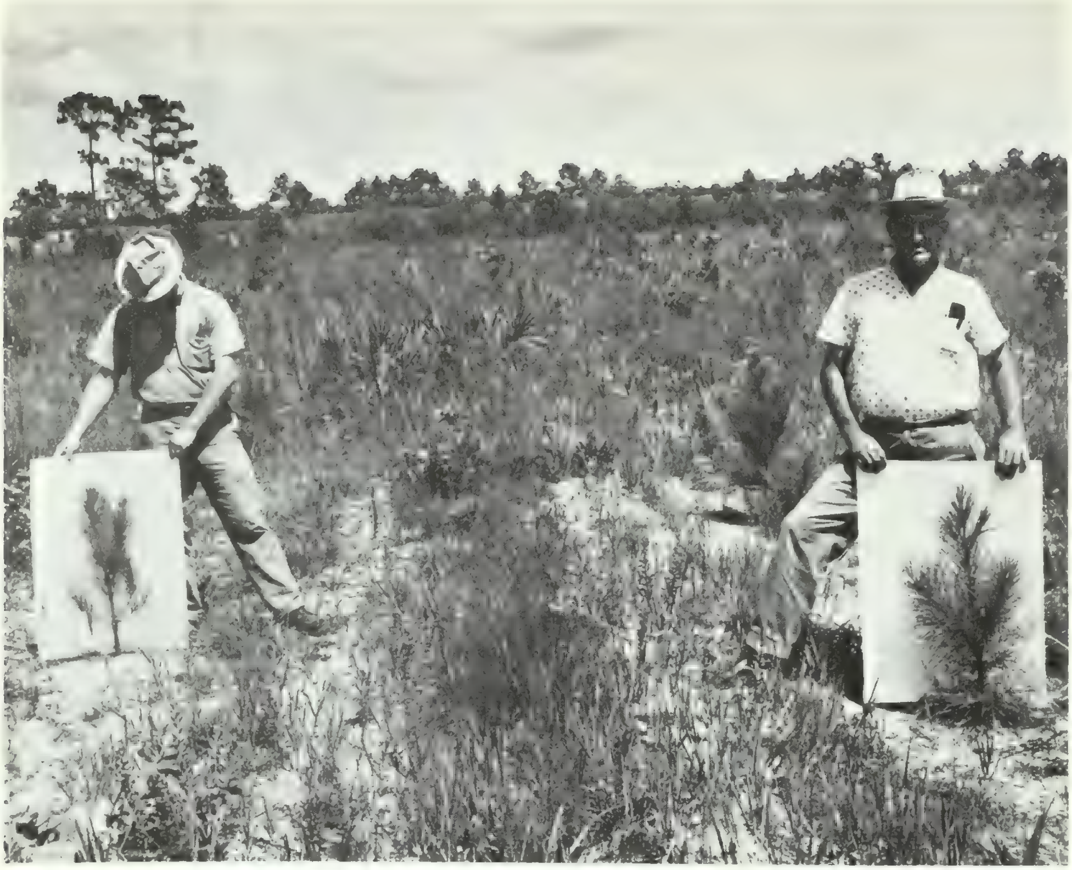


Figure 3.--On an excessively drained site, slash pine seedlings had higher survival but no better growth in deep furrows (right) than in scalped strips (left).

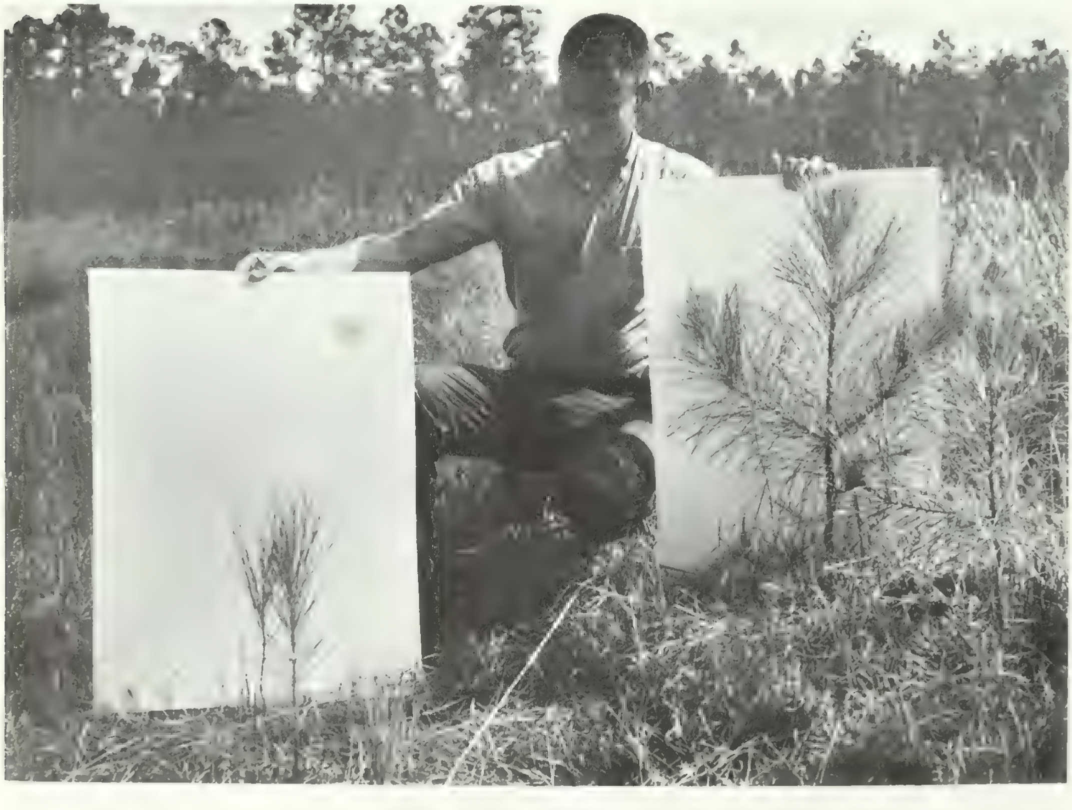


Figure 4.--On a poorly drained site, slash pine seedlings survived and grew better on beds than in furrows, whether planted in the summer, fall, or winter.

The seedlings lifted earliest had very succulent tips that were subject to breakage during handling and to temporary wilting after planting. Terminal buds were seldom visible, and secondary needles were just emerging. Under slightly more rigorous planting-site environments, mortality of these seedlings might have been much greater. Seedlings with perhaps one more month of growth and development in the nursery beds would be much better planting stock. Preliminary results from a 1966 study indicate that sowing in nursery beds in late November will produce good planting stock by late June.

ADVANTAGES OF TWO PLANTING SEASONS

McGregor recognized several advantages of planting both summer and winter: "Nursery lifting, packing, and shipping would be less seasonal. Planting equipment could be used and experienced planting crews could be employed during a greater part of the year; consequently, fewer men and less equipment would be required to accomplish a given planting program."

As summer planting progresses toward an operational basis, additional advantages are becoming apparent. Two sowing seasons probably will be necessary to produce optimum-sized seedlings for both summer and winter planting, and this should reduce the 12-hour days and 7-day weeks nursery crews often work while preparing and sowing nursery beds. The addition of a second sowing season and a second lifting season would tend to level out the rush and slack periods now associated with nursery work.

Foresters in Florida generally prefer to prepare sites in the summer or early fall for winter planting. The soil has resettled by winter, yet vegetative competition is still light. Some large industrial ownerships, however, must operate their site preparation equipment year around to keep ahead of their ambitious planting programs. If these companies can plant winter and summer, more plantations will become established under optimum planting site conditions.

SUMMARY AND RECOMMENDATIONS

Bare-rooted slash pine seedlings were outplanted in the summers of 1963 and 1964 in northeastern Florida. Survival following most of the summer plantings was more than adequate, although not so high as that of the winter plantings.

Planting during the summer rainy season in northeastern Florida could be a welcome supplement to the established winter planting season, which is curtailed by dry autumns and springs. An unqualified recommendation for summer planting might better be delayed, however, until results are available from current operational summer plantings on various sites throughout Florida and southeastern Georgia.

For the interim, these tentative recommendations for summer planting of slash pine in northeastern Florida are offered:

1. Plant between late June and late September, for this is the period that normally receives adequate rainfall.

2. Lift seedlings only if they average at least 6 inches in height and have numerous secondary needles. Sowing nursery beds in late November has produced satisfactory seedlings by late June; sowing in early March has produced them by early August.

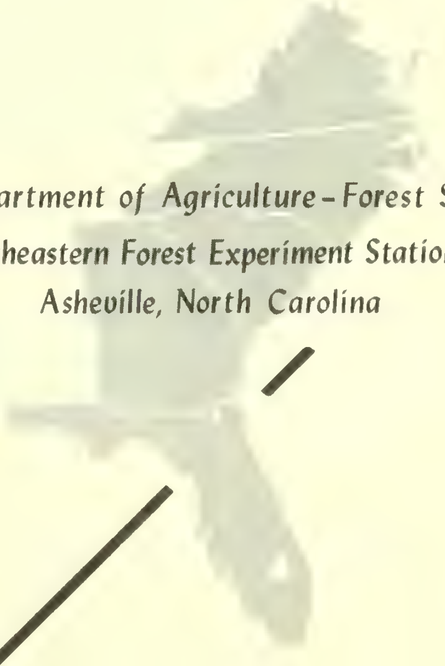
3. Plant within a day after lifting if possible; for longer storage periods, refrigeration above freezing temperatures appears to be beneficial.

4. As in winter planting, plant when the soil is moist.

U. S. Forest Service Research Paper SE-24 December 1966

Performance of Two Slash Pine Varieties Planted in South Florida

by
James E. Bethune



U.S. Department of Agriculture-Forest Service
Southeastern Forest Experiment Station
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Performance of Two Slash Pine Varieties Planted in South Florida

by

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More slash pine (Pinus elliottii Engelm.) is planted in the southeastern United States than any other tree species. In southern Florida, land managers must choose between the typical variety and the native South Florida slash pine (Pinus elliottii var. densa Little & Dorman). A 9-year-old planting of the two slash pine varieties on the Corkscrew Experimental Forest[1] provides comparisons of survival, early growth, insect and disease resistance, and other characteristics which will be of value to those interested in plantation establishment in Florida. These results should be considered tentative. The two varieties must be observed over a full rotation period to establish definitely their relative characteristics.

South Florida slash pine was described as a separate variety by Little and Dorman (1954). Seedlings of the South Florida variety are almost stemless, with crowded needles and thick taproots. Sapling-size South Florida slash pine have relatively thicker stems and branches, and longer needles than the more slender typical variety (fig. 1). Langdon (1963) and Ward (1964) have published maps delineating the area of natural distribution of the two slash pine varieties in south Florida. Squillace (1966) found that the two varieties differ appreciably in several traits of needles, buds, seedling form, etc., but are not discrete genetic entities. A transition zone characterized by clinal variation occurs in south-central Florida.

Methods

South Florida slash pine seed used in the study were collected in Hendry County, Florida; seed of the typical slash pine variety were from a source in Baker County, Florida. Seedlings of both varieties were grown in the Alico Land Development Company's Keri Nursery in Hendry County.

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[1] A Collier County, Florida, tract owned by Alico Land Development Company and leased for forest research to the Southeastern Forest Experiment Station in cooperation with the Florida Board of Forestry.

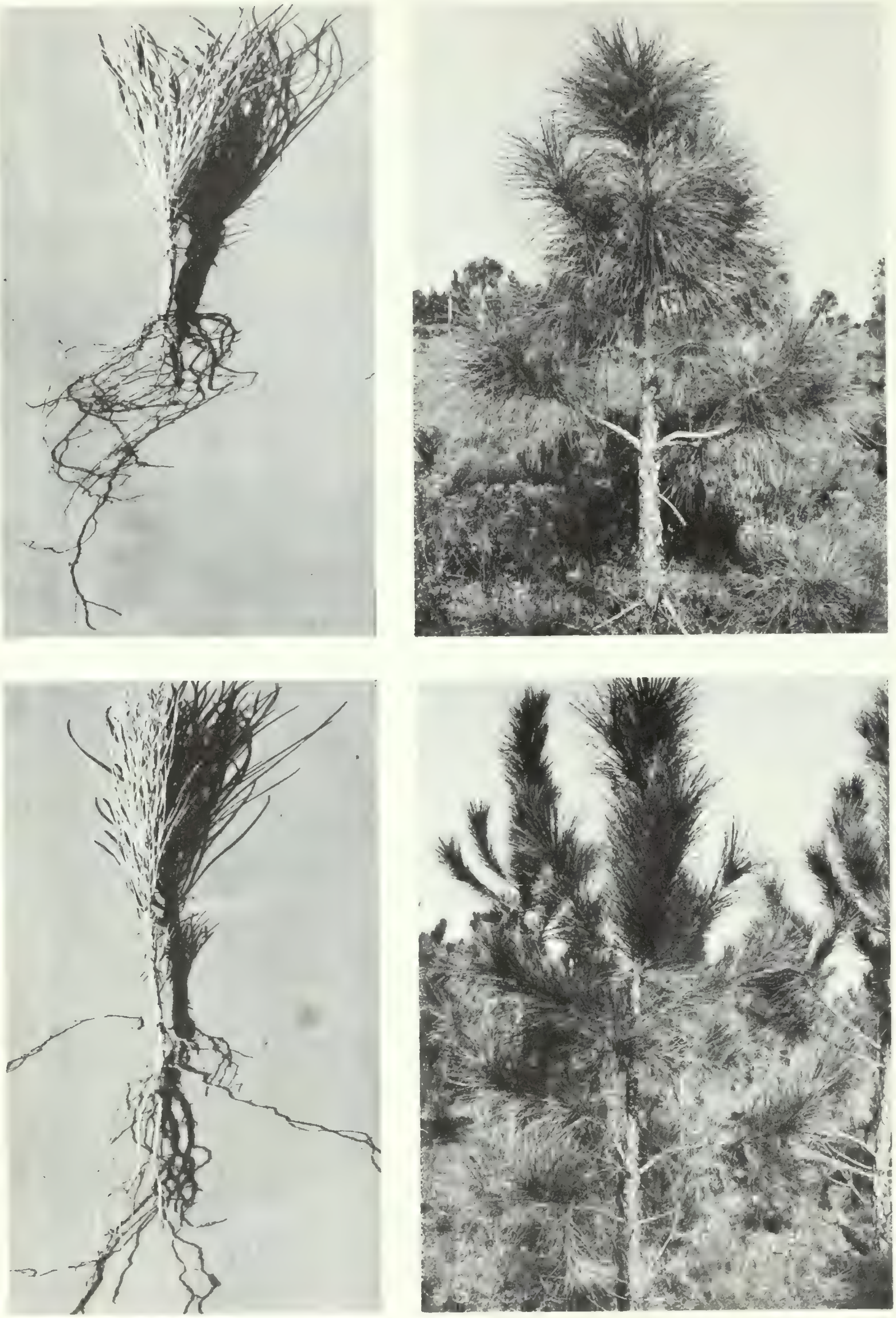

Figure 1.--Seedling- and sapling-size South Florida slash pine (above) and typical slash pine (below).

Nursery-run seedlings were handplanted at a spacing of 6 by 8 feet in a palmetto-wiregrass rough in January 1954, with 8 replications of 50 trees each for each variety. The soil, a Leon fine sand, is a typical pine flatwoods acid sand underlain by an organic stain layer at a depth of about 24 inches. Survival, height, and presence of insects and diseases were recorded at time of planting and at 1, 3, 5, and 9 years after planting. Diameters of trees over 4.5 feet tall were recorded at ages 5 and 9.

In September 1960, 7 years after planting, Hurricane Donna subjected the planting to winds in excess of 100 miles per hour. Damage resulting from the storm was recorded, and roots of blown down, leaning, and erect trees of both varieties were dug up and compared.

Survival

Survival was fair for typical slash pine and poor for South Florida slash (table 1); differences between varieties were significant.[2] Mortality of South Florida slash pine averaged over 5 percent per year, and the rate of mortality decreased only slightly after age 5. Typical slash pine mortality was negligible after the first year.

The continued mortality of the South Florida slash pine was related to infection by brown spot needle blight disease, caused by Scirrhia acicola (Dearn.) Siggers. Eighty-nine percent of the trees that died after age 3 were infected by this fungus.

Table 1.--Average survival of South Florida slash pine and typical slash pine, by age

Age from planting (years)	South Florida slash	Typical slash
	- - Percent - -	
1	77	77
3	70	76
5	62	76
9	50	76

Height Growth

Typical slash pine was significantly taller than South Florida slash pine from the time of planting through age 9. The difference in average height, based on surviving trees, increased slightly during the later years of the study (fig. 2). Mean annual height growth since age 3 was 2.4 feet for the 40 tallest typical slash pines, compared with 2.2 feet for the 40 tallest South Florida slash pines.

Height distribution curves of the two varieties differed appreciably (fig. 3). Typical slash pine heights were distributed normally, whereas South Florida slash pine height distribution took the form of a shallow

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[2] In this paper significant and highly significant relate to the 5 and 1 percent levels of probability, respectively.

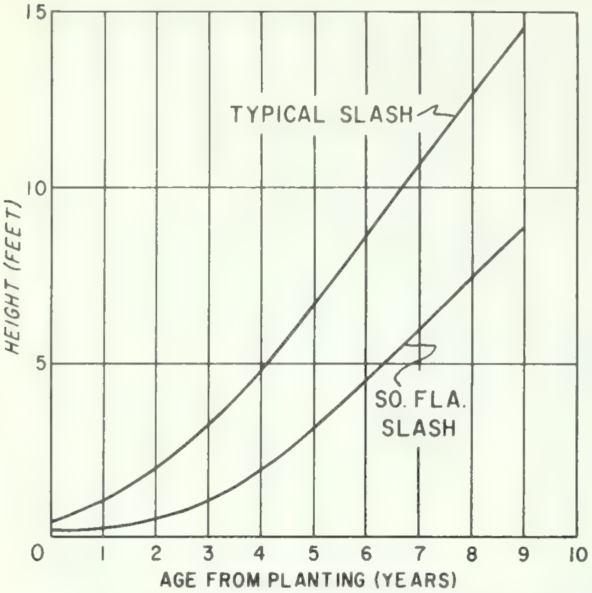

Figure 2.--Average height of the two slash pine varieties, by age.

curve with two peaks. The first peak reflects the large number of seedlings which failed to begin height growth. The flattened shape of the major peak resulted from greater inherent variability in growth of this variety.

Diameter Growth

At age 5, South Florida slash pine diameters at breast height averaged 1.0 inch, compared with 1.1 inches for typical slash pine. By age 9, diameters were 2.5 inches and 2.9 inches, respectively. South Florida slash pine diameters averaged 0.28 inch per foot of height, compared with 0.19 inch per foot of height for the typical slash variety.

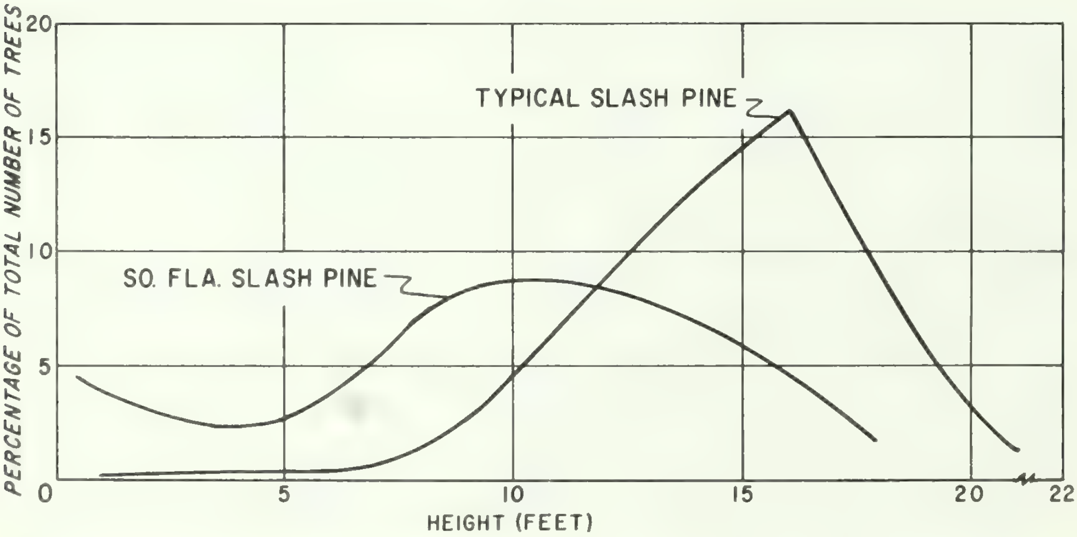

Figure 3.--Height distribution at age 9 as a percentage of total number of South Florida slash pine and typical slash pine trees.

Regression analysis with diameter as the dependent variable and height and density[3] as independent variables resulted in equations which were significantly different for mean and slope. Above 8 feet in height South Florida slash pine maintained an advantage in diameter for a given height and density. Regressions of double bark thickness on diameter at breast height for the two varieties at age 9 were not significantly different.

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[3] Density was expressed on a plot basis as square feet per surviving tree at age 9.

Differences in bark thickness were more pronounced 1 foot above the ground than at 4.5 feet. At 1 foot, South Florida slash pine double bark thickness at age 9 averaged 0.2 inch greater than typical slash pine bark for all heights and diameters.

Hurricane Damage

Hurricane Donna damaged a larger percentage of South Florida slash pine than typical slash pine (table 2). The difference in amount of damage between varieties was highly significant.

The more open stands resulting from poorer survival of the South Florida slash accounted for some of the variation in susceptibility to damage. Covariance analysis to adjust number of trees damaged for varying stand densities reduced the difference between adjusted means, but the difference remained significant. Adjustment of number of trees damaged for variations in height failed to reduce the difference between varieties.

Table 2.--Effects of Hurricane Donna on South Florida slash pine and typical slash pine by damage classifications

Classification	South Florida slash	Typical slash
	- - Percent - -	
Undamaged	46	77
Leaning < 30°	29	15
Leaning between 30° and 60°	14	6
Leaning > 60°	10	2
Blown down	1	0

Much of the difference between varieties in susceptibility to wind damage was explained by the survey of root development of damaged and undamaged trees. Most damaged trees, regardless of variety, had deformed or underdeveloped roots. Roots of undamaged trees were, for the most part, well developed (fig. 4).

Six years after the hurricane, the leaning trees appear thrifty and are growing as well as undamaged adjacent trees. Height growth since the storm is oriented vertically and the trees are severely crooked (fig. 5). This condition will impair, but not destroy, their value for pulpwood.

Insect and Disease Damage

Tip moths (Rhyacionia spp.) attacked typical slash pine severely between 3 and 7 years after outplanting. Seventy percent of the leaders were tip moth infested at age 5. Death of infested leaders resulted in poor form of the sapling-size trees. The effect of these attacks on form is still evident on many of the trees at age 9. Few fresh attacks have occurred since age 5.

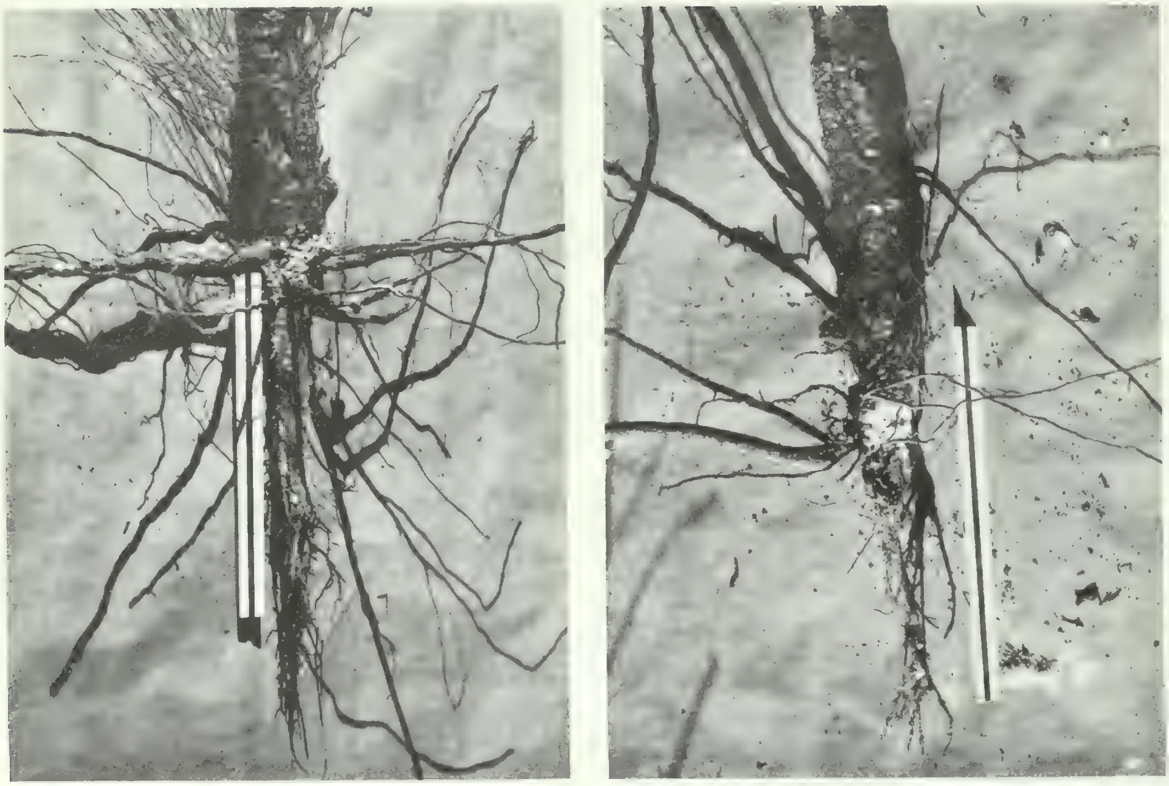

Figure 4.--South Florida slash pine root systems. Tree with well-developed roots (left) was undamaged by hurricane. Tree with malformed roots (right) was blown down.

Pine webworm (Tetralopha robustella) and pine sawflies (Neodiprion spp.) were observed on both varieties in endemic numbers.

Brown spot needle blight disease is closely associated with mortality and poor growth in South Florida slash pine. Eighty-nine percent of the seedlings which died after age 3 were infected with brown spot disease, and none of these seedlings reached 1 foot in height.

Pitch canker, caused by the fungus Fusarium lateritium f. pini, a disease often found in south Florida, has not been a problem in this planting. There is, however, an association between tip moth and pitch canker (Matthews 1962), and the disease may develop in later years.

Discussion

Large, carrot-shaped roots and short stems make South Florida slash pine seedlings difficult to plant correctly, and contribute to the relatively poor survival of planted seedlings. When this study was installed, proper nursery techniques for growing South Florida slash pine were not fully understood. The seedlings were spindly and were not root-pruned. Production of better nursery stock and application of improved planting techniques (Bethune 1963; Langdon 1958) have resulted in improved survival in most South Florida slash pine plantings. Even so, typical slash pine planted in southern Florida can be expected to maintain meaningfully better average survival than South Florida slash pine.

Failure to initiate prompt height growth is a major problem with planted South Florida slash pine. Growth and survival of trees which begin height growth during the first season after planting often compare favorably with growth and survival of typical slash pine. Much of the variation in early height growth within the variety can be eliminated by stringent nursery grading (Langdon 1958). The correlation between incidence of brown spot disease, failure to begin height growth, and subsequent mortality indicates that control of this disease may result in greatly improved survival and growth.

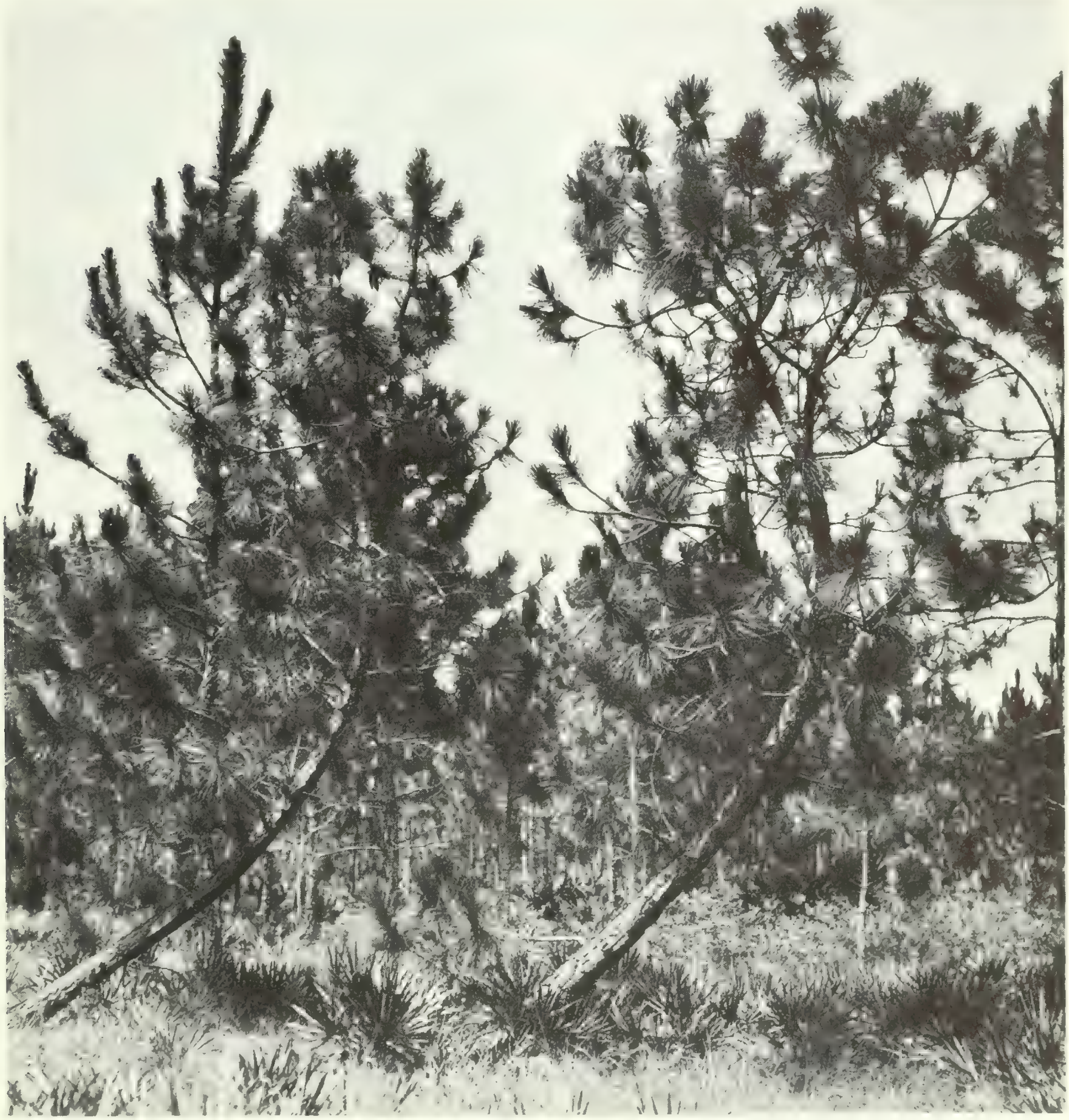

Figure 5.--South Florida slash pine 6 years after Hurricane Donna. Leaning trees have become severely crooked.

The typical variety of slash pine has consistently grown faster than South Florida slash pine in this and other plantings. There is no evidence at present that South Florida slash pine will eventually equal or exceed the growth of typical slash pine. A final answer on relative growth rates must wait until present plantings are older.

Differences in root development and susceptibility to windthrow between the varieties apparently result from improper planting. Root pruning and care in placing roots in the planting slit should eliminate these differences. The denser South Florida slash pine foliage presents more resistance to the wind and may be a factor affecting susceptibility to wind damage in young plantations prior to crown closure.

The greater bark thickness of South Florida slash pine gives the variety an advantage in fire resistance--an important consideration in south Florida, where fires are common (Ketcham and Bethune 1963). South Florida slash pine also has an advantage in resistance to insects and diseases except brown spot disease. The greater wood density of South Florida slash pine is usually considered an advantage. However, recent work suggests that differences in density may be environmentally rather than genetically controlled (White and Saucier 1966).

There is evidence that cattle damage has less impact on subsequent growth of South Florida slash than on typical slash (Hilmon et al. 1963). In southern Florida, where much of the land is managed for both timber and cattle, resistance to grazing damage is an important consideration.

The advantages of the two varieties when planted in south Florida are:

South Florida slash pine

1. Fire resistance.
2. Relative resistance to insect and disease attack once height growth has begun.
3. Relatively less growth loss following cattle damage.
4. Safety factor of resistance to elements of the environment associated with planting a native species.

Typical slash pine

1. Better survival and early growth.
2. Less brown spot disease.
3. Resistance to wind damage.

The decision as to which slash pine variety is better suited for southern Florida planting must be made by the individual landowner after considering his objectives and resources. Once the decision is made, maximum success will depend on adapting the methods of growing, handling, and planting to the requirements of the variety.

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DIAMETER DISTRIBUTIONS IN NATURAL YELLOW-POPLAR STANDS

by

Charles E. McGee and Lino Della-Bianca

Cover photo: A Southern Appalachian yellow-poplar stand with a wide variety of diameters.

Southeastern Forest Experiment Station
Asheville, North Carolina
Forest Service
U.S. Department of Agriculture

DIAMETER DISTRIBUTIONS IN NATURAL YELLOW-POPLAR STANDS

by

Charles E. McGee, Silviculturist

and

Lino Della-Bianca, Associate Silviculturist

EXCELLENT STANDS of yellow-poplar grow on fertile, well-drained coves, lower slopes, and bottom lands in the Southern Appalachian mountains. These elite stands make up only a small portion of the mountain forest, but, because of their productivity, they are of great importance to the mountain economy.

Foresters and timber owners need information that will help them plan the intensive management these stands should have. This paper presents the diameter distributions found in pure, unthinned stands of yellow-poplar. These distributions represent the natural development of the number of trees in specific size classes in relation to stand age, site index, and total number of stems per acre. If what has happened in the past is a good indicator of what will happen in the future, the stand descriptions should be very valuable for answering questions that must be decided in stand management planning. For instance, will it pay to thin a yellow-poplar stand on a moderate site at age 30, or will the trees to be thinned be too small to make a merchantable cut? Of course, in yellow-poplar stands the production of high-value veneer logs outweighs most every other consideration. Therefore, another important question is, will there be enough veneer-size stems on the site at age 60 to justify a harvest cut, or will the number of veneer-size trees increase enough to warrant waiting until age 70?

Admittedly, these data will not answer all questions, and someday more accurate criteria based on remeasurement of managed stands will probably become available. Meanwhile, the value of these diameter distributions is already being proved.

Methods

Plot Selection

Data for this study were obtained from 141 circular ¼-acre plots established in the Appalachian Mountains of North Carolina (93 plots), Virginia (31 plots), and Georgia (17 plots). Site index, stand age, and number of trees per acre, by 1-inch diameter classes, were obtained on each plot.

To be included in the study, a stand had to have 75 percent or more of its overstory in yellow-poplar. All the stands were even-aged and ranged from 17 to 76 years of age. Site index at age 50 ranged from 75 to 150 feet, and basal area varied from 44 to 208 square feet per acre. The maximum and minimum number of yellow-poplar trees per acre, by stand age and site index, are shown in table 1.

Sampled stands were free of disease and insects and showed no evidence of past cutting. Trees were well distributed over the plot.

TABLE 1.—*Minimum and maximum observed numbers of yellow-poplar trees per acre by age and site index classes.*

Site index (Feet at age 50)	Age (years)						
	< 21	21-30	31-40	41-50	51-60	61-70	> 70
< 81				220 220			
81-90		228 228	240 320		140 168	72 196	
91-100		160 380	256 256	100 172	96 208	72 232	68 140
101-110		176 364	136 252	48 272	84 272	100 192	
111-120		152 252	152 332	136 212	132 156	88 176	
121-130	216 216	236 396	124 256	96 188	152 152	136 136	
131-140		164 328	140 204				
> 140	184 184						

Analysis

Analysis of the data to determine diameter distributions followed procedures developed by Clutter and Bennett for planted slash pine.[1]

Our objective was to present a table of the number of trees per acre by 1-inch diameter classes for various combinations of age, site index, and total number of trees per acre. Basal area per acre was used in the initial computations, rather than number of trees, because basal area allowed a more accurate description of the number of trees in the larger diameter classes.

The curve form used to determine the proportion of basal area for trees in any 1-inch diameter class was:

$$f(Di) = \frac{\Gamma(\alpha+\beta+2)}{\Gamma(\alpha+1)\ \Gamma(\beta+1)} \left(\frac{Di - Dmin}{Dmax - Dmin}\right)^{\alpha} \left(1 - \frac{Di - Dmin}{Dmax - Dmin}\right)^{\beta}$$

where,

$f(Di)$ = relative frequency of basal area per acre for diameter Di;

α and β = parameters to be estimated from the data;

$Dmax$ = maximum diameter of trees in the stand;

$Dmin$ = minimum diameter of trees in the stand ($Dmin$ was set at 4.5 inches, the smallest trees measured).

The basal area in any 1-inch diameter class was converted to number of trees per class per acre by the relationship:

$$Ni = Pi\,\frac{BA}{Bi}$$

where,

Ni = number of trees in the i^{th} diameter class;

Pi = proportion of the total basal area per acre that lies in the i^{th} diameter class ($i = 5, 6, \ldots 27$);

BA = total basal area per acre;

Bi = basal area per tree for the midpoint tree in the i^{th} diameter class ($i = 5, 6, \ldots 27$).

The predicted values of α, β, and $Dmax$ were obtained from the following equation:

$$\hat{\alpha} = 13.02839 - 0.02546\,(\text{Age}) - \left(\frac{66.84692}{\text{Age}}\right)$$
$$-4.43671\ (\text{Logarithm of number of trees})$$
$$-0.04678\left(\frac{\text{Site index} \times \text{number of trees}}{1000}\right)$$

$R^2 = 0.476$ Standard error $= 0.582$

$$\hat{\beta} = 1.21499 - 0.12504\left(\frac{\text{Age} \times \text{site index}}{1000}\right)$$

$R^2 = 0.129$ Standard error $= 0.450$

$$\hat{Dmax} = 9.38123 + 2.41398\left(\frac{\text{Age} \times \text{site index}}{1000}\right)$$
$$-0.35928\left(\frac{\text{Age} \times \text{number of trees}}{1000}\right)$$

$R^2 = 0.700$ Standard error $= 2.09$

Actual values of α, β, and $Dmax$ were plotted over calculated values. No bias was apparent in any case.

Results and Discussion

The expected number of trees by 1-inch diameter classes was calculated for various combinations of age, site index, and total number of trees per acre. These values are presented in tables 2 through 6. Although the tables are useful, they have several limitations. Neither the tables nor the equations involved in their development describe changes in basal area and number of trees that occur on a given site with time. Such changes can be determined only by periodic remeasurements of permanent plots. To apply the tables, one must assume that a certain number of trees per acre will be present at a given time.

We also recognize that managed stands of the future will not have diameter distributions exactly like those reported here for unmanaged stands, because cleanings and thinnings will remove smaller size classes. It is to be hoped there will be more large trees than are shown in the tables.

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[1] Clutter, Jerome L., and Bennett, Frank A. Diameter distributions in old-field slash pine plantations. Ga. Forest Res. Counc. Rep. 13, 9 pp., illus. 1965.

Because of these limitations the use of the tables for predicting the performance of any particular managed yellow-poplar stand is restricted. Nevertheless, the growth of these stands is the best available indicator we have of future stand behavior, and the availability of diameter distributions will allow much more sophisticated stand management planning than has been possible in the past. The choice of future thinning schedules and rotation ages can now be based on stem size as well as on total volume and basal area.

Careful study of the tables provides considerable information relevant to thinning certain types of yellow-poplar stands. For instance, should the owner of a yellow-poplar stand on site 100 land plan on thinning at age 30? For this example we will assume a stand density of 250 stems per acre.[2] Under these site and stand stipulations, a thinning from below would consist mostly of 5- and 6-inch trees and would reduce the basal area of the stand below 87 square feet per acre. The decision whether or not to plan on a 30-year thinning in this stand must be left with the individual landowner, but we do recommend further study of the 40-year diameter distribution before a final decision is made.

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[2] McCarthy, E. F. Yellow poplar (*Liriodendron tulipifera* L.) characteristics, growth, and management. U.S. Dep. Agr. Tech. Bull. 356, 58 pp., illus. 1933. Table 17 in this publication supplies average number of yellow-poplar stems found in natural stands in relation to age and site index.

TABLE 2.—*Diameter distributions for pure natural yellow-poplar stands by age and stand density per acre on site index 90.*

Total trees (Number)	Basal area (Square feet)	Number of trees per diameter class (inches)																						
		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Age 20																								
100	33	15	21	19	16	12	9	5	3															
150	38	48	37	25	17	11	7	4	1															
200	43	95	47	26	15	9	5	2	1															
250	48	145	53	26	14	7	4	1	--															
300	54	194	57	26	13	6	3	1	--															
350	61	242	61	26	12	6	2	1	--															
Age 30																								
100	51	3	8	13	14	15	14	12	10	7	4													
150	61	12	23	25	24	21	17	13	9	5	1													
200	70	29	39	36	30	24	18	13	8	3	--													
250	77	51	56	46	35	26	18	11	6	1	--													
300	84	77	72	54	39	27	17	10	4		-													
350	90	105	87	62	42	28	17	8	1	--	--													
Age 40																								
50	44	--	--	1	2	4	5	6	6	7	7	6	4	2										
100	67	1	4	8	10	12	12	12	12	11	9	6	3	-										
150	82	5	14	18	20	20	18	16	14	11	8	5	1	--										
200	91	14	27	30	29	26	22	19	15	10	6	2	--	--										
250	98	28	42	42	37	31	25	19	14	9	3	--	-	-										
300	106	44	59	53	44	35	27	19	13	6	--	-												
350	113	62	75	64	51	39	28	19	10	2	--			-										
Age 50																								
50	55	--	--	1	1	2	3	4	5	5	6	6	6	5	4	2								
100	82	1	3	5	7	9	10	11	11	10	10	9	7	5	2	--								
150	98	4	10	14	16	17	17	16	14	13	11	9	6	3	--	-								
200	110	10	21	25	25	24	22	19	17	14	11	8	4	--	-	--								
250	117	21	34	36	34	30	26	22	18	14	10	5	--	-	-	--								
300	123	34	49	48	42	36	30	23	18	12	7	1	--	-	--	--								
Age 60																								
50	68	-	--	--	1	2	2	3	3	4	4	5	5	5	5	5	4	2						
100	98	1	2	4	6	7	8	9	9	9	9	9	8	7	6	4	2	--						
150	116	3	8	12	14	14	14	14	14	13	12	10	9	7	5	1	--	--						
200	125	9	19	22	22	22	20	19	16	14	12	10	8	5	2	--	--	--						
250	130	19	31	33	31	28	25	22	18	15	12	9	6	1	--	--	-	--						
Age 70																								
50	80	--	--	--	1	1	2	2	3	3	3	4	4	4	4	5	4	4	4	2				
100	114	1	2	4	5	6	7	7	7	8	8	8	7	7	7	6	5	4	1	--				
150	132	3	8	11	12	13	13	12	12	11	11	10	9	8	7	5	4	1	--					
200	141	9	18	20	20	19	18	17	15	14	12	11	9	8	6	4	--	--	--	--				
250	146	19	30	30	28	26	23	20	17	15	13	11	9	6	3	-	--		-					

Potential stem sizes can have a definite bearing on selecting rotation ages. Tables 2 through 6 show how stem sizes are distributed in older natural stands. For example, land with site index 100 and 100 stems per acre produced 15 trees 19 inches d.b.h. or larger in 60 years. In 70 years, 27 trees larger than 18 inches were produced. Each owner can decide whether the increase in veneer-size trees is worth waiting 10 years to harvest.

The information presented here describes the development of yellow-poplar stands under natural unmanaged conditions. The stands described in the tables represent the last opportunity foresters will have to observe natural stand development over a wide range of conditions, because most yellow-poplar stands in the future will come under management at an early age.

TABLE 3. --*Diameter distributions for pure natural yellow-poplar stands by age and stand density per acre on site index 100.*

Total trees (Number)	Basal area (Square feet)	Number of trees per diameter class (inches)																						
		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
										Age 20														
100	35	13	20	19	16	12	9	6	4	1														
150	41	43	36	26	18	12	8	5	2	--														
200	46	84	48	29	18	11	6	3	1	--														
250	52	129	56	30	17	10	5	2	1	--														
300	58	173	63	31	17	9	5	2	--	--														
350	65	214	71	34	17	9	4	1	--	--														
										Age 30														
100	56	2	7	11	13	14	14	12	11	8	6	2												
150	68	9	20	23	22	20	18	14	11	8	4	1												
200	77	23	35	34	30	25	20	15	10	6	2	--												
250	87	40	50	44	36	28	21	15	10	5	1	--												
300	94	60	66	54	42	31	22	15	8	2	--	--												
350	103	79	81	64	48	34	23	14	7	--	--	--												
										Age 40														
50	48	--	--	1	2	3	4	5	6	6	6	6	6	4	1									
100	74	1	4	6	9	10	11	11	11	11	9	8	6	3	--									
150	91	4	11	16	18	18	17	16	15	13	10	8	4	--	--									
200	104	11	22	26	27	25	22	20	16	13	10	6	2	--	--									
250	113	21	35	38	35	31	27	22	17	13	8	3	--	--	--									
300	122	32	49	49	43	37	30	24	18	12	6	--	--	--	--									
350	131	44	63	60	52	43	34	25	17	10	2	--	--	--	--									
										Age 50														
50	62	--	--	1	1	2	2	3	4	4	5	5	6	6	5	4	2							
100	95	1	2	4	6	7	8	9	10	10	10	9	8	7	6	3	--							
150	113	3	8	12	13	15	15	15	14	13	12	10	9	7	4	--	--							
200	127	8	17	21	22	22	21	19	17	15	13	11	8	5	1	--	--							
250	137	14	28	31	31	29	26	23	20	17	14	10	6	1	--	--	--							
300	147	23	39	42	39	36	31	27	22	18	13	8	2	--	--	--	--							
										Age 60														
50	76	--	--	--	1	1	2	2	3	3	4	4	4	5	5	5	4	4	3					
100	115	--	2	3	5	6	7	7	8	8	8	8	8	8	7	6	5	4	--					
150	137	2	6	10	11	12	13	13	13	12	11	11	10	9	7	6	4	--	--					
200	150	6	14	18	19	19	19	18	16	15	14	12	10	9	7	4	--	--	--					
250	159	13	24	27	27	26	24	22	20	17	15	13	10	8	4	--	--	--	--					
										Age 70														
50	92	--	--	--	1	1	1	2	2	2	3	3	3	4	4	4	4	4	4	4	3	1		
100	136	--	2	3	4	5	5	6	6	7	7	7	7	7	7	6	6	6	5	4	--	--		
150	157	2	6	9	10	11	11	11	11	11	10	10	9	9	8	7	6	6	3	--	--	--		
200	169	7	14	16	17	17	17	16	15	14	13	12	10	9	8	7	6	2	--	--	--	--		
250	179	13	23	25	25	23	22	20	18	16	15	13	11	10	8	6	2	--	--	--	--	--		

TABLE 4.—*Diameter distributions for pure natural yellow-poplar stands by age and stand density per acre on site index 110.*

Total trees (Number)	Basal area (Square feet)	Number of trees per diameter class (inches)																						
		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Age 20																								
100	37	11	18	18	16	13	10	7	5	2														
150	44	38	35	26	19	13	9	6	3	1														
200	50	74	48	30	20	13	8	5	2	--														
250	56	113	58	34	20	12	7	4	2	--														
300	63	150	68	37	21	13	7	3	1	--														
350	72	184	78	41	23	13	7	3	1	--														
Age 30																								
100	60	2	6	10	12	13	13	12	11	9	7	4	1											
150	74	8	17	20	21	20	18	15	12	10	6	3	--											
200	86	18	30	32	29	25	21	17	13	9	5	1	--											
250	97	31	44	42	36	30	24	18	13	8	4	--	--											
300	107	45	59	52	43	35	26	19	13	7	1	--	--											
350	117	59	72	63	51	39	29	20	12	5	--	--	--											
Age 40																								
50	54	--	--	1	2	2	3	4	5	5	6	6	6	5	4	1								
100	83	1	3	5	7	9	10	10	11	10	10	9	7	5	3	--								
150	104	3	9	13	15	16	16	16	15	13	12	10	7	4	1	--								
200	117	8	18	23	24	24	22	20	18	15	12	9	6	1	--	--								
250	129	15	29	33	33	30	27	24	20	16	12	8	3	--	--	--								
300	142	23	40	43	41	37	32	27	22	17	12	6	--	--	--	--								
350	154	30	51	53	50	44	38	31	24	17	10	2	--	--	--	--								
Age 50																								
50	70	--	--	--	1	1	2	3	3	4	4	5	5	5	5	5	4	3						
100	109	--	2	3	5	6	7	8	8	9	9	9	8	8	7	6	4	1						
150	131	2	6	9	12	13	13	14	13	13	12	11	10	9	7	5	1	--						
200	148	5	13	17	19	20	20	19	17	16	14	13	11	8	6	2	--	--						
250	161	10	22	26	27	27	25	23	21	19	16	14	11	7	2	--	--	--						
300	175	16	30	35	35	34	31	28	24	21	18	14	10	4	--	--	--	--						
Age 60																								
50	89	--	--	--	1	1	1	2	2	2	3	3	4	4	4	4	5	4	4	4	2			
100	133	--	1	2	4	5	6	6	7	7	7	8	8	7	7	7	6	6	4	2	--			
150	161	2	5	8	9	10	11	11	11	11	11	11	10	9	9	8	7	5	2	--	--			
200	177	4	11	15	16	17	17	16	16	15	14	13	12	10	9	8	6	1	--	--	--			
250	190	9	19	22	24	23	22	21	20	18	16	15	13	11	9	7	1	--	--	--	--			
Age 70																								
50	109	--	--	--	--	1	1	1	1	2	2	2	3	3	3	4	4	4	4	4	4	4	3	
100	159	--	1	2	3	4	5	5	6	6	6	6	6	6	7	6	6	6	6	5	5	3	--	
150	184	2	5	7	8	9	9	10	10	10	10	9	9	9	8	8	7	7	6	5	2	--	--	
200	209	4	10	13	14	15	15	14	14	13	13	12	11	10	10	9	8	7	6	2	--	--	--	
250	220	9	17	20	21	21	20	19	18	16	15	14	13	12	11	9	8	6	1	--	--	--	--	

TABLE 5.—*Diameter distributions for pure natural yellow-poplar stands by age and stand density per acre on site index 120.*

Total trees (Number)	Basal area (Square feet)	Number of trees per diameter class (inches)																						
		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
										Age 20														
100	39	10	17	17	16	13	10	8	5	3	1													
150	46	33	33	26	20	15	10	7	4	2	--													
200	54	64	47	32	22	15	10	6	3	1	--													
250	62	97	59	37	23	15	9	6	3	1	--													
300	70	128	70	42	26	16	10	6	2	--	--													
350	80	154	82	48	29	18	11	6	2	-	-													
										Age 30														
100	67	1	5	8	10	12	12	12	11	10	8	6	4	1										
150	82	6	15	18	19	19	18	16	13	11	8	5	2	--										
200	95	14	26	29	28	25	22	18	15	11	8	4	-	--										
250	108	24	38	39	35	31	26	21	16	11	7	2	-	--										
300	121	34	50	49	43	36	30	23	17	11	6	1		--										
350	134	42	62	59	52	43	34	26	18	11	3	--	--	--										
										Age 40														
50	59	--	--	1	1	2	3	3	4	5	5	5	6	5	5	4	1							
100	93	1	2	4	6	8	9	9	10	10	9	9	8	7	5	3	-							
150	114	2	8	11	14	15	15	15	14	13	12	11	9	7	4	--	--							
200	133	6	15	19	21	22	21	20	18	16	14	12	9	6	1	--	--							
250	148	11	23	28	29	29	27	24	22	19	15	12	8	3	-	--	-							
300	163	16	32	37	38	36	32	29	25	21	16	12	6	--	-	--	--							
350	180	20	40	46	46	43	39	34	29	23	17	11	2	-	-	--	--							
										Age 50														
50	79	-	--	--	1	1	1	2	3	3	3	4	4	5	5	5	5	4	3	1				
100	122	-	1	3	4	5	6	7	8	8	8	8	8	8	7	7	6	5	1	--				
150	149	1	5	8	10	11	12	12	12	12	12	11	11	10	9	7	5	2	--	--				
200	172	4	10	14	16	17	18	17	17	16	15	14	12	11	9	7	3	--	--	--				
250	188	7	17	21	24	24	23	22	21	19	18	16	14	11	8	4	--	-	--	--				
300	206	10	23	29	31	31	29	28	26	23	20	18	15	11	6	--	--	-	--	--				
										Age 60														
50	98	--	--	--	1	1	1	1	2	2	2	3	3	3	4	4	4	4	4	4	4	3		
100	154	--	1	2	3	4	4	5	6	6	6	7	7	7	7	7	7	6	6	5	4	—		
150	185	1	4	6	8	9	10	10	10	10	10	10	10	9	9	9	8	7	6	4	-	--		
200	208	3	8	12	14	14	15	15	15	14	14	13	12	11	11	10	8	7	4	--	--	--		
										Age 70														
50	121	-	--	--	--	--	1	1	1	1	2	2	2	3	3	3	3	4	4	4	4	4	4	4
100	189	--	1	2	2	3	3	4	4	5	5	5	6	6	6	6	6	6	6	6	6	5	5	2
150	223	1	3	5	7	7	8	8	9	9	9	9	9	8	8	8	8	8	7	7	6	5	1	--

TABLE 6.—*Diameter distributions for pure natural yellow-poplar stands by age and stand density per acre on site index 130.*

Total trees (Number)	Basal area (Square feet)	Number of trees per diameter class (inches)																						
		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Age 20																								
100	41	9	16	16	15	13	11	8	6	4	2													
150	50	29	31	26	20	15	11	8	6	3	1													
200	59	55	45	33	23	17	11	8	5	2	1													
250	67	82	58	39	27	18	12	8	4	2	--													
300	77	106	71	46	31	20	13	8	4	1	--													
350	89	125	83	54	36	23	15	9	4	1	--													
Age 30																								
100	73	1	4	7	9	11	11	11	11	10	9	7	6	3										
150	91	4	12	16	18	18	17	16	14	12	10	7	5	1										
200	105	11	22	26	26	25	22	19	16	13	10	7	3	--										
250	121	18	32	35	34	31	27	23	19	14	10	6	1	--										
300	137	24	42	45	42	37	32	26	21	16	10	5	--	--										
350	154	29	51	54	50	44	38	31	24	17	10	2	--	--										
Age 40																								
50	65	--	--	--	1	2	2	3	3	4	4	5	5	5	5	5	4	1						
100	104	--	2	4	5	6	8	8	9	9	9	9	8	8	7	5	3	--						
150	128	2	6	9	12	13	14	14	14	13	12	11	10	9	7	4	--	--						
200	150	4	12	16	19	20	20	19	18	17	15	13	11	9	6	1	--	--						
250	170	8	18	24	26	26	26	24	22	20	18	15	12	8	3	--	--	--						
300	190	11	25	31	33	33	32	29	27	24	20	16	12	7	--	--	--	--						
350	211	13	30	38	41	40	38	36	32	28	23	18	11	2	--	--	--	--						
Age 50																								
50	89	--	--	--	--	1	1	2	2	2	3	3	4	4	4	5	5	5	4	4	1			
100	138	--	1	2	3	4	5	6	7	7	7	8	8	8	7	7	7	6	5	2	--			
150	171	1	4	6	8	10	10	11	11	11	11	11	11	10	9	9	8	6	3	--	--			
200	195	3	8	12	14	15	16	16	16	15	15	14	13	12	11	9	7	4	--	--	--			
250	221	5	13	17	20	21	21	21	20	19	18	17	16	14	12	10	6	--	--	--	--			
Age 60																								
50	116	--	--	--	--	1	1	1	1	1	2	2	2	3	3	3	4	4	4	4	4	4	4	2
100	176	--	1	2	2	3	4	4	5	5	6	6	6	6	6	7	6	6	6	6	6	5	2	--
150	217	1	3	5	6	7	8	9	9	9	9	9	9	9	9	9	9	8	7	7	6	2	--	--
Age 70																								
50	125	--	--	--	--	--	1	1	1	1	2	2	2	2	3	3	3	3	4	4	4	4	5	5
100	206	--	1	1	2	3	3	3	4	4	5	5	5	5	5	6	6	6	6	6	6	6	6	6

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A Reproducible System for Evaluating Forest Fire Retardants

by

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[illegible] & AGR. DIV.

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A Reproducible System for Evaluating Forest Fire Retardants

by

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Many fire-retardant chemicals are being offered to forest firefighters by manufacturers because the use of chemicals to fight forest fires throughout the United States is steadily increasing. These proprietary products generally contain one or more chemicals known for their fire-retardant effectiveness. With several basic chemicals or proprietary fire-retardant products from which to choose, the fire control officer needs guidance as to what material should be used in his particular area. With this objective in mind, we have developed a reproducible method for rating the effectiveness of the basic fire-retardant chemicals--a relative rating in which the degree of superiority or inferiority of different amounts of the various chemicals can be determined.

Similar work has been done in the past. After making more than 800 tests on wood cribs, Tyner[1] was able to rate the fire extinction effectiveness of water solutions of 33 chemical compounds in several concentrations. The most promising materials tested were the ammonium phosphates and phosphoric acid.

More recently, Hardy et al.[2] conducted laboratory experiments in which fuel beds of pine needles were treated with several proprietary fire-retardant products and burned. The results indicated the comparative effectiveness of particular chemical formulations in reducing the intensity of fires burned under controlled conditions.

The work reported here was divided into two parts. The major part involved the burning of treated wood cribs of uniform construction in a combustion room under static air conditions. The second part involved repeating certain of the burning tests on retardant treated cribs in a wind tunnel solely to see if the relative chemical ratings under static conditions would be maintained under wind conditions.

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[1] Tyner, Howard D. Fire extinguishing effectiveness of chemicals in water solution. Ind. and Eng. Chem. 33: 60-65. 1941.

[2] Hardy, C. E., Rothermel, R. C., and Davis, J. B. Evaluation of forest fire retardants--a test of chemicals on laboratory fires. U. S. Forest Serv. Intermountain Forest and Range Exp. Sta. Res. Pap. 64, 33 pp. 1962.

PROCEDURE - PART I

An inherent problem in trying to establish a reproducible test is controlling all the variables, other than the test variable, that could mask the results. A fuel was chosen that could be easily reproduced. Cribs were constructed of white fir sticks, cut to a cross section of $\frac{1}{4}$ by $\frac{1}{4}$ inch (± 0.003 inch). A standard-size crib 30$\frac{1}{4}$ inches long, 9$\frac{1}{4}$ inches wide, and 5 inches high (fig. 1) was used for the static portion of the tests.

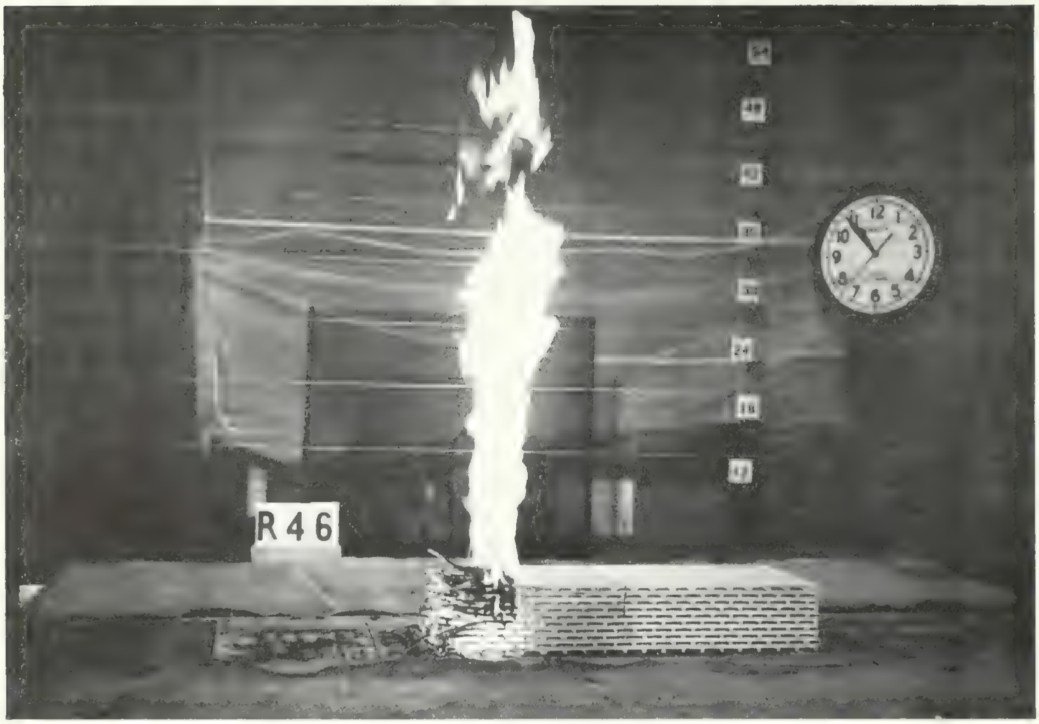

Figure 1.--Part of this burning test crib is treated with fire retardants; part is untreated. Effectiveness of retardants is determined by measurements of flame spread and related factors.

Crib Construction

The cribs were assembled by alternating tiers of short and long sticks set perpendicular to each other. Spacing between short and long sticks within each tier was 1$\frac{1}{2}$ inches at stick centers. A total of 20 tiers, 10 of short and 10 of long sticks, made up a crib 5 inches high.

Most of the white fir dimension lumber from which the sticks were cut had a density range between 0.30 and 0.52 gram per cubic centimeter. A narrower range was needed to control the effect of density on fire spread. Therefore, the processed sticks were divided into three relatively narrow density classes: Class I - 0.30 to 0.36, Class II - 0.361 to 0.44, and Class III - 0.441 to 0.52 gram per cubic centimeter.

Because of the inherent differences in fires among the three groups, a separate analysis was made for cribs within each density class. A large proportion of the processed sticks was in density Class II; therefore, most of the chemicals were tested on cribs of this class.

Crib Treatment and Conditioning

All chemicals tested were mixed with water as a carrier. The cribs were dipped one-half their length into the retardant mix, and then spun in a centrifuge at 150 r.p.m. for 30 seconds. This system assured uniform distribution of material on the treated portion and gave a reproducible test. If too much chemical is applied to the treated portion of the crib, the fires will not reach a steady state of fire spread, but will be extinguished. In such a case no point on the effectiveness curve can be plotted, and no comparisons between chemicals according to chemical amount used could be made. Following treatment, the cribs were conditioned at 59 to 60 percent relative humidity until they reached an equilibrium moisture content of about 10 percent.

The amount of dry chemical retained was calculated from the weight of wet retardant remaining on the crib after it was treated. For example, if a retardant solution contained 15 percent chemical by weight, then the wet weight of solution applied to a fuel multiplied by 0.15 is equal to the calculated dry weight of the chemical retained (wet weight x 0.15 = dry weight). The total retention of salt was controlled by altering the solution concentration, or by increasing solution viscosity with industrial gum thickeners to increase thickness of the solution film on the crib surface.

Within each density class, several cribs were individually treated with sodium calcium borate and diammonium phosphate (DAP). This plan fulfilled a twofold purpose: (1) to determine whether the relative effectiveness of the two chemicals differed by fuel density, and (2) to see how the relative effectiveness of newer chemicals compared with the effectiveness of the borate and the DAP in any of the density classes.

Chemicals Used

The following chemicals were tested for fire-retardant effectiveness: sodium calcium borate, diammonium phosphate (DAP), monoammonium phosphate (MAP), ammonium phosphate liquid concentrate (11-37-0), dibasic calcium phosphate, ammonia-superphosphate, ammonium sulfate, ammonium sulfamate, bentonite, and attapulgite.

Crib Burning

The cribs were burned in still air in a combustion room (32 feet high by 32 feet square) that had been conditioned to a relative humidity range of 58 to 62 percent. Air temperature in the room was not so closely controlled. The fires were started in the untreated end of the cribs and allowed to burn through the treated portion. The cribs were of adequate length to permit the fires to reach a steady state of fire spread through both the untreated and treated portions of the cribs.

A total of 61 cribs was burned to complete this portion of the study. Of these, 18 were of density Class I, 35 were of Class II, and 8 of Class III.

Measurements

While fires burned through the untreated and treated portions of the cribs, continuous measurements of flame height, rate of flame spread, radiant heat, and convective heat were recorded, respectively, by means of a time-lapse camera, stopwatch, Gier and Dunkle radiometers, and a thermocouple system over the flame front.

PROCEDURE - PART II

Methods of fuel-bed construction, crib treatment, and crib burning were generally the same for the wind-tunnel tests as for the static tests, with the following necessary exceptions.

A different size crib was constructed. Stick size and spacing were the same, but crib length was 60 inches and crib height was 2 inches. The additional length was needed to permit the fire to reach a steady rate of spread in the untreated and treated portions of the crib. The 2-inch height was judged to be adequate to get relative differences in spread rates due to retardant treatment.

Sticks of only Class II density were used; only one wind speed, 5 feet per second, was generated during these tests.

Three chemicals were tested during the wind-tunnel trials--diammonium phosphate, ammonium sulfate, and sodium calcium borate. We chose these chemicals because they represented a wide range in retardant effectiveness according to the static-test trials. The borate was shown to be the least effective fire retardant, while DAP was the best, and ammonium sulfate was intermediate. Only rate of spread was recorded for these test fires.

CHEMICAL RATINGS

Static Tests

As expected, the rates of spread in untreated portions of the test cribs differed according to density class.[3] Untreated Class I, Class II, and Class III cribs burned at an average rate of 3.01, 2.50, and 2.09 inches per minute, respectively.

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[3] Fons, W. L., Clements, H. B., Elliott, E. R., and George, P. M. Project fire model, summary progress report - II. U. S. Forest Serv. Southeast. Forest Exp. Sta., 55 pp. 1962.

The variables measured during the crib tests were plotted by density class over "dry chemical retained per unit surface area" of wood in the treated crib. Curves of similar slope resulted, regardless of variable used. To simplify the chemical comparisons, only the rate-of-spread variable was chosen as a graphic representation of retardant effectiveness.

The effect of chemicals on rate of fire spread in the static tests is outlined by curves plotted in figures 2, 3, and 4. The chemical with the steepest curve is the most effective. Since some of the plotted curves are not straight lines, a ratio of the DAP curve equation to the other chemical equations will not reliably describe the relative effectiveness of the chemicals at all points along the curve. Instead, a comparison of the amount of chemical needed to produce low rates of spread that approach flame extinction seems the most plausible (table 1).

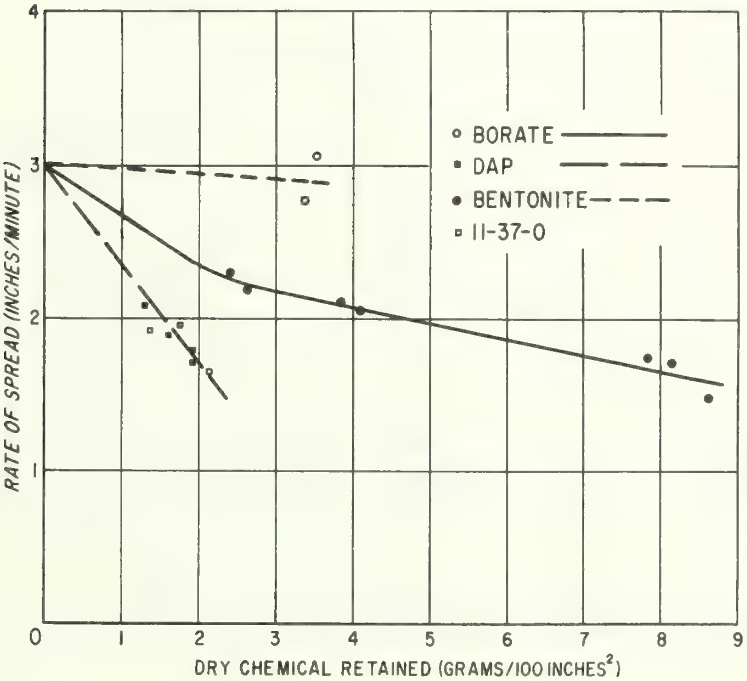

Figure 2.--Performance of fire-retardant chemicals in static-burning tests of cribs of Class I density. The steeper the curve, the more effective the chemical. (See table 1 for related data.)

The ratios derived in table 1 directly reflect the magnitude of the superiority of one chemical over another as regards fire-retardant effectiveness. If chemical effectiveness and cost were the only factors to consider in choosing an operational chemical, a firefighter could easily calculate which one would do the job at the least cost. The ratio of DAP effectiveness to other chemicals is in reality an "inferiority" factor of the other chemical. The product of the inferiority factor and a unit-weight cost reflects what the firefighter would have to pay for the same amount of work done by any of the rated chemicals. Thus, if 4 units of borate (ratio of 4) is needed to do the work of one unit of DAP, the cost of the borate would have to be less than one-fourth of the DAP cost per unit of chemical to have a working advantage over DAP. New or promising fire-retardant chemicals can easily be given a permanent rating with this system.

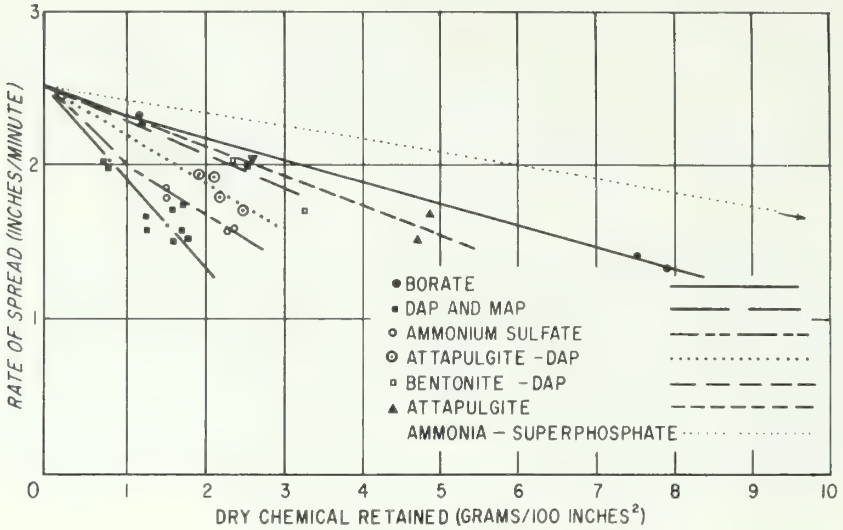

Figure 3.--Performance of fire-retardant chemicals in static-burning tests of cribs of Class II density. The steeper the curve, the more effective the chemical. (See table 1 for related data.)

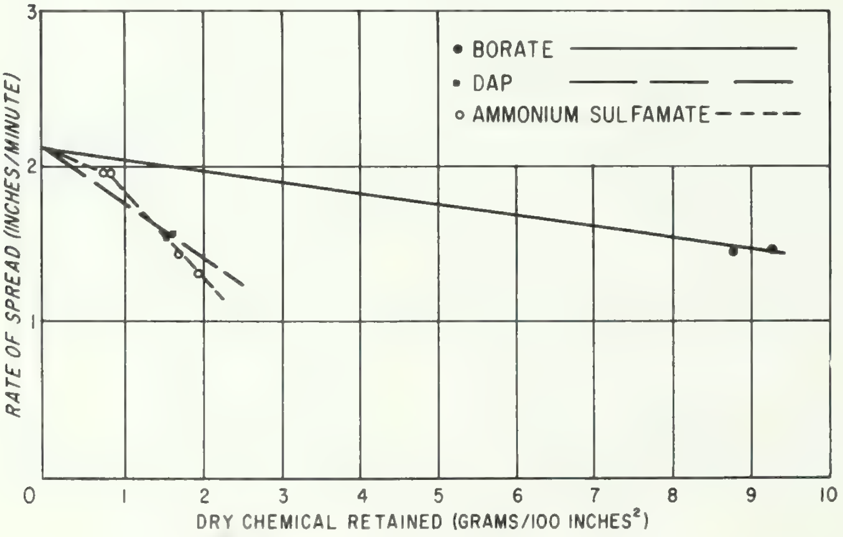

Figure 4.--Performance of fire-retardant chemicals in static-burning tests of cribs of Class III density. The steeper the curve, the more effective the chemical. (See table 1 for related data.)

Although retardant effectiveness and cost are of primary importance, other factors such as chemical toxicity to animals and plants, corrosiveness to metal, and handling properties must also be examined before the chemical can be considered for operational use.

Other phosphate chemicals tested in addition to DAP were monoammonium phosphate (MAP), 11-37-0 liquid phosphate concentrate, and orthophosphate, a mixture of DAP and MAP. The plotted points of these phosphates fell on or near the plotted DAP curve. Therefore, the effectiveness of these phosphate chemicals tested was assumed to be approximately equal (fig. 2).

Table 1.--Amount of chemical needed to reduce flame spread to 1½ and 1 inch per minute

Wood density class	Chemical used	Chemical needed[1]		Ratio to DAP	
		1½-inch rate	1-inch rate	1½-inch rate	1-inch rate
		- - - Grams - - -			
I	DAP	2.30	3.08	1.0	1.0
I	11-37-0	2.30	3.08	1.0	1.0
I	Borate	9.50	14.20	4.1	4.6
I	Bentonite	--	--	10.+	10.+
II	DAP	1.64	2.47	1.0	1.0
II	MAP	1.64	2.47	1.0	1.0
II	Borate	6.75	10.10	4.1	4.1
II	Ammonium sulfate	2.51	3.95	1.5	1.6
II	Attapulgite-DAP	3.22	4.85	2.0	2.0
II	Bentonite-DAP	4.56	6.86	2.8	2.8
II	Attapulgite	5.22	7.85	3.2	3.2
II	Ammonia-superphosphate	11.71	17.50	7.1	7.1
III	DAP	1.72	3.30	1.0	1.0
III	Borate	8.45	16.40	4.9	5.0
III	Ammonium sulfamate	1.59	2.49	0.9	0.8

[1] Weight per 100 square inches of fuel surface.

There are strong indications that the ammonia portion of the ammonium phosphates contributes little or nothing to the fire-retardant capabilities of the chemicals. The 15-percent DAP solution used in the Class II cribs had an N-P-K fertilizer content of 3.15-7.95-0, while the 13-percent MAP solution had an N-P-K content of 1.56-7.93-0. A common effectiveness line was plotted for both chemicals. The phosphate fraction can be noted as being essentially the same, but twice as much ammonia was present in the DAP solution. If the ammonia had a fire-retardant effect, each chemical should have produced a separate effectiveness curve.

Only one new chemical, ammonium sulfamate, was tested in Class III cribs. It was somewhat inferior to DAP at low application rates, but appeared superior to DAP at higher applications.

Ammonium sulfate was not as efficient as DAP for slowing fire advance. One and one-half parts of the sulfate were needed to do the work of one part phosphate.

Attapulgus clay showed some promise as a fire retardant (one-third as good as DAP). There was some conjecture as to whether using this clay as a thickener of DAP solutions would increase the effectiveness of the salt. Actually, the clay cut the effectiveness of the DAP in half, as shown in table 1.

Bentonite could also be used as a thickener of DAP if the clay was hydrated before the salt was added to the system. A chemical reaction occurred immediately, however, and the resultant retardant mixture was even less effective than attapulgus-DAP.

Superphosphate, relatively insoluble in water, was thickened through the addition of aqua ammonia and water. The resultant retardant did a poor job of slowing flame spread.

Wind-Tunnel Tests

Although results of the wind-tunnel tests were curvilinear (fig. 5), the retardant-effectiveness relationship of DAP, ammonium sulfate, and borate was similar to that derived under static conditions (table 2). This means that the relative effectiveness of the chemical retardants is not greatly affected when there is a change from static to wind conditions; and the static tests can be considered a reliable measure of retardant effectiveness. Wind does, however, bring about the need for more of all chemicals in a fuel to keep the rate of fire spread at a low level.

When comparing the amounts of chemicals needed to bring about several rates of flame spread, DAP was computed to be about three times more effective than borate and about 1.4 times more effective than ammonium sulfate (table 2). These comparisons are reasonably close to those ratios derived under static conditions, 4.1 and 1.5 times for the borate and sulfate, respectively from table 1.

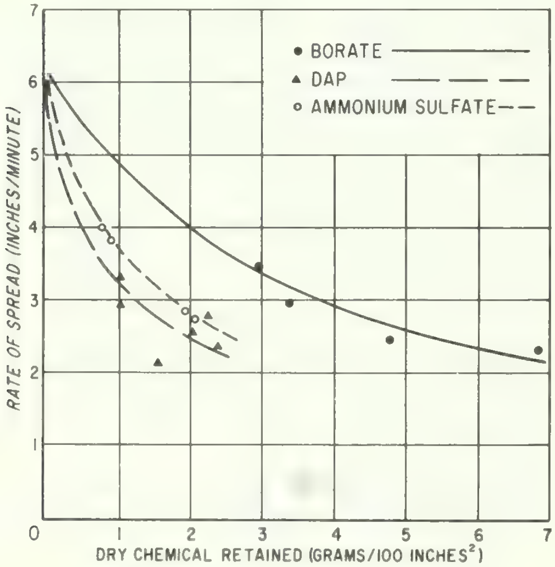

Figure 5.--Although performance of fire-retardant chemicals in Class II cribs burned in the wind tunnel indicated a need for more chemicals under wind conditions, the relative effectiveness of the retardants was similar to that found under static conditions.

Table 2.--Flame spread in 5-feet-per-second wind as related to amount of chemicals retained

Rate of flame spread	Chemical retained			Ratio: DAP to others	
	DAP	Sulfate	Borate	Sulfate	Borate
Inches/minute	- Grams/100 square inches -				
4.0	0.48	0.80	2.00	1.67	4.17
3.0	1.22	1.72	3.70	1.41	3.03
2.5	1.95	2.55	5.20	1.31	2.67

SUMMARY

A method for testing the effectiveness of fire-retardant chemicals on woody fuels has been developed. The test involves the use of a preconstructed wood crib, one-half of which is treated with a fire retardant. The speed with which flames pass through the treated portion of the crib is plotted over the weight of dry chemical present. A regression curve is plotted for each chemical that reflects treatment effectiveness in accordance with amount of chemical present. The most effective chemical has the steepest curve. Of the chemicals tested, the best "effectiveness" ratings belong to ammonium sulfamate, ammonium phosphates (DAP, MAP, and 11-37-0), and ammonium sulfate in that order.

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Density and Height Growth in Natural Slash Pine

by

Arthur B. Collins III

U.S. Department of Agriculture-Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

Density and Height Growth in Natural Slash Pine

by

Arthur B. Collins III

Slash pine (Pinus elliottii Engelm.) seed trees surrounding two newly abandoned cotton fields on the George Walton Experimental Forest, Dooly County, Georgia, released a bumper seed crop during October and November 1947. Sampling 3 years after seedfall showed concentrations of seedlings as high as 50,000 per acre. To investigate the effect of release on dense slash pine reproduction, we installed three treatments in March 1951: (1) thinning to single trees at 10- by 10-foot spacing; (2) thinning to clumps of 6 to 8 trees at 10- by 10-foot spacing; and (3) an unthinned check. The design constituted a randomized complete block, with two replications in each field. Plot size was approximately 1/4 acre in the larger field and 1/5 acre in the smaller field.

Two men, using a wheeled buggy saw, did the thinning. Perpendicular swaths were first cut across the plots, leaving clumps of 6 to 8 trees. In plots designated for single-tree treatment, the clumps were thinned by hand. Figure 1 shows a portion of the study stand as it appeared in March 1951.

Total height and d.b.h. were last measured in December 1964, 14 growing seasons after treatment. Height measurements were made on 25 dominant and codominant trees in each plot. Trees were selected within the unthinned check plots at a spacing of approximately 10 by 10 feet. Within each treatment, the diameter of every tree was measured on 50-foot-square permanent plots.

HEIGHT GROWTH

As evidenced by a range of 17 feet in mean plot heights among treatments, density (trees per acre) adversely affected total height growth of dominant and codominant trees (table 1). Analysis of variance proved trees on the single-tree and clump plots to be significantly taller

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At the time of this study, Arthur B. Collins III was Research Forester with the Southeastern Forest Experiment Station, Cordele, Georgia. He is now with State and Private Forestry, Southeastern Area, Atlanta, Georgia.

than trees on the check plot[1] but not to differ significantly themselves. It is interesting to note that this density effect holds within as well as among treatments.

Depth to a fine textured soil horizon, an important determinant of slash pine height growth,[2] varied from 4 to 26 inches among plots. Considering the chance that the block effect of the study design did not adequately remove this source of variation, depth to fine texture was included with density in a covariance analysis. Density continued to show a highly significant effect on mean height after adjustment for site differences.

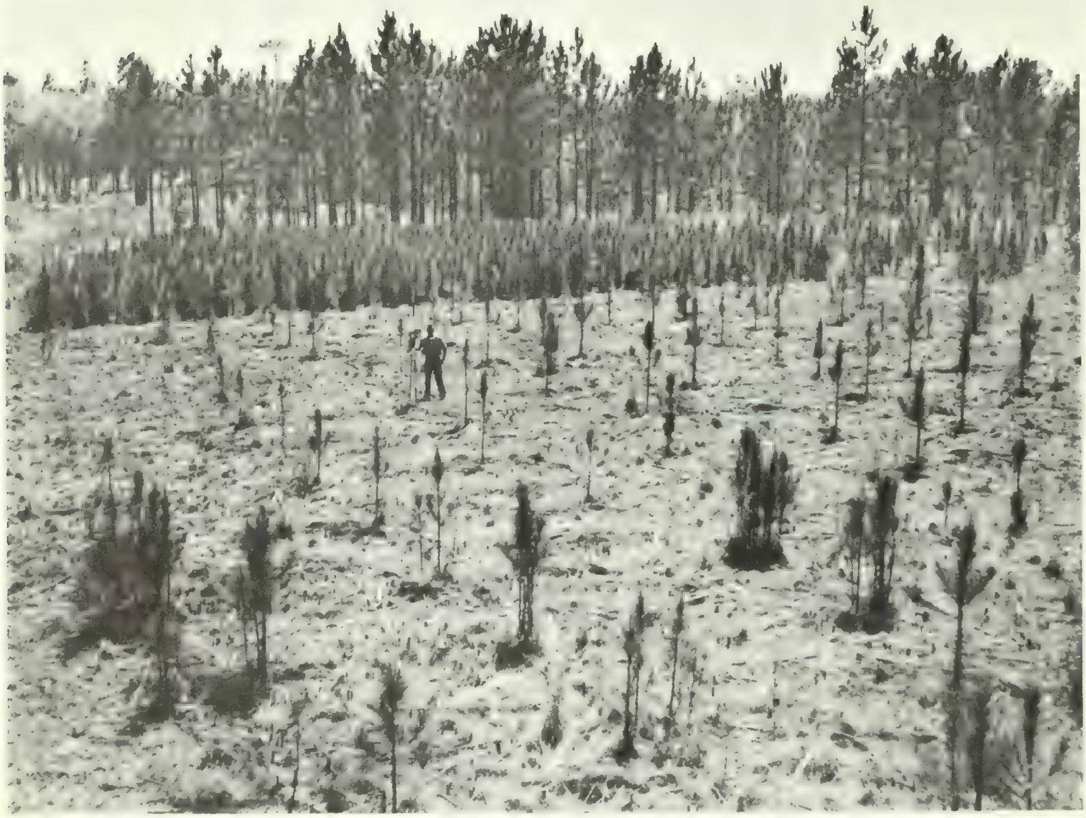

Figure 1.--Three plots as they appeared following thinning treatment of March 1951: clump treatment (front), single-tree treatment (where man stands), and unthinned check (rear).

In a regression analysis, trees per acre accounted for 78 percent of the variation in dominant height. Height decreases approximately 1 foot for each 500-tree increase in density (fig. 2).

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[1] Using Duncan's new multiple range test at the 95 percent confidence level.

[2] Coile, T. S. Soil productivity for southern pines--longleaf, slash and pond pines. Forest Farmer XI(8): 11-12. 1952.

Table 1.--Total height,[1] diameter breast high, and density 14 years after treatment (17 years from seed)

Block	Check			Clump			Single-tree		
	Height	D. b. h.	Density	Height	D. b. h.	Density	Height	D. b. h.	Density
	Feet	Inches	Trees per acre	Feet	Inches	Trees per acre	Feet	Inches	Trees per acre
1	33.9	2.5	4,513	41.6	4.7	697	44.6	7.0	436
2	37.7	3.2	2,925	44.6	4.8	662	43.9	6.8	331
3	27.7	1.7	8,816	37.0	3.0	2,021	41.7	6.5	366
4	28.1	2.0	6,795	30.3	2.5	2,422	39.6	5.9	331
Mean	31.8	2.4	5,762	38.4	3.8	1,450	42.4	6.6	366

[1] Average height of 25 dominant and codominant trees per plot.

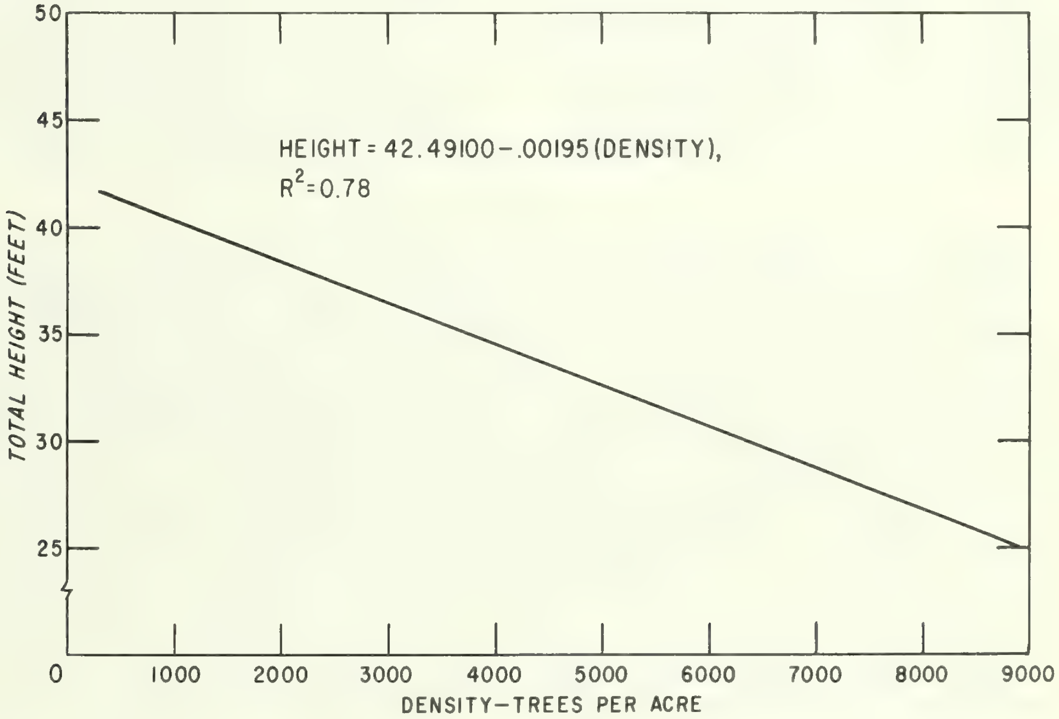

Figure 2.--In 14 years, thinned trees were as much as 15 feet taller than unthinned.

The height-density pattern that developed in this study is also apparent in the spacing study on slash pine on the George Walton Experimental Forest.[3] Comparison of eight spacings at age 12 shows tree height is positively correlated with spacing. Although the trend is not entirely consistent, measurements at age 14 show that it is strengthening.

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[3] Harms, W. R., and Collins, A. B. III. Spacing and twelve-year growth of slash pine. J. Forest. 63: 909-912. 1965.

DIAMETER GROWTH

Average diameter among treatments at age 17 ranges from 1.7 to 7.0 inches (table 1) and is negatively correlated with density (fig. 3). The average diameter class of a 330-tree-per-acre stand is 2 inches larger than one on a stand averaging 660 trees per acre. Beyond densities of 1,500 trees per acre, mean diameter declines very slowly as density increases. For instance, average diameter decreases from 3.5 inches on stands averaging 1,500 trees per acre to only 1.6 inches on stands averaging 9,000 trees per acre. Some of the differences in mean d. b. h. are due to site variation since the effect of this variable has not been removed by the regression in figure 3.

Comparison of diameter distributions among treatments 14 years after thinning shows very few trees of merchantable size at the higher densities (table 2). Although individual plot data are not shown, 2 inches (with only one exception) is the mode diameter class for all plots containing more than 2,000 trees per acre. Less than 2 percent of the trees in the unthinned plots are of merchantable size. In contrast, more than 96 percent of the trees on single-tree plots are of merchantable size (fig. 4).

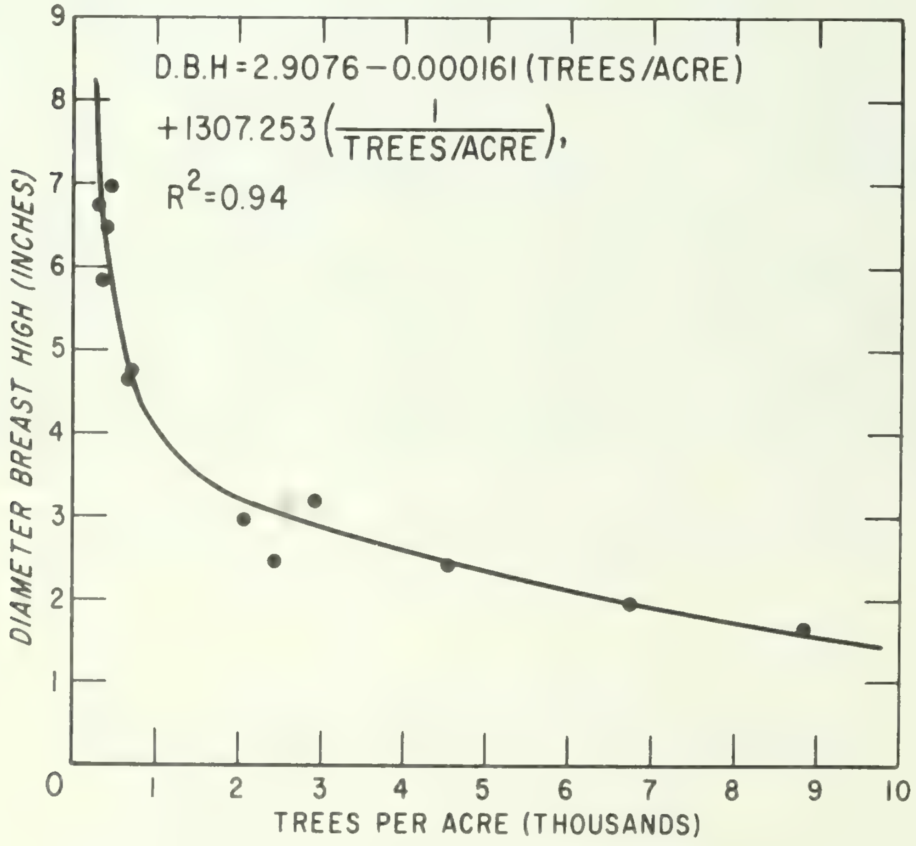

Figure 3. --In 14 years, thinning has accelerated diameter growth among densities less than 1,500 trees per acre.

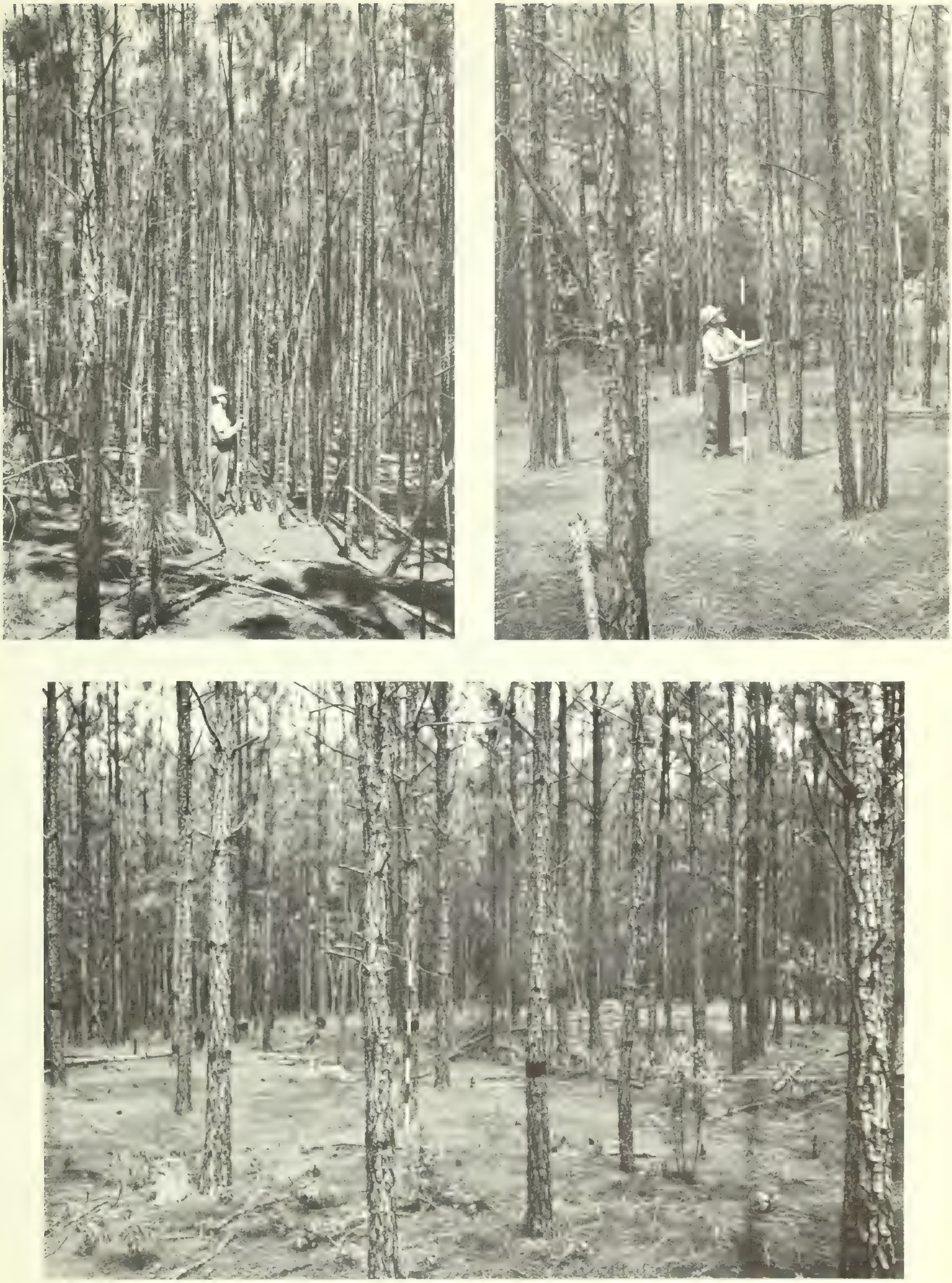

Figure 4. --Check (upper left), clump (upper right), and single-tree (lower) plots 14 years after treatment (17 years from seed).

Table 2.--Diameter distribution by 1-inch diameter classes, 14 years after treatment (17 years from seed)

D. b. h. class	Check	Clump	Single-tree
	Trees per acre		
1	1,492	235	--
2	2,764	418	--
3	1,119	296	4
4	299	183	9
5	78	148	48
6	10	105	113
7	--	39	113
8	--	26	66
9	--	--	13
Total	5,762	1,450	366

CROWN RATIO

Differences in diameter growth among treatments are largely due to variation in crown size, although competition for soil moisture and nutrients at the extreme densities undoubtedly has some effect. Live-crown ratio was measured on each sample dominant or codominant tree. Statistically, all treatment means differ significantly at the 5-percent level. Percent crown ratios are:

Check	Clump	Single-tree
26.3	39.0	44.1

Crown ratio in the check plots has dropped below the 30 percent minimum live crown, the point at which accepted practice specifies thinning. Measurements in the check and clump plots represent maximum values since only dominant and codominant trees were measured. If all trees were measured, crown ratio of the single-tree treatment would remain about the same.

VOLUME PRODUCTION

Thinning significantly increased cubic-foot volume production (table 3). For instance, single-tree plots average 16.8 cords per acre and clump plots 9.9 cords per acre, but merchantable volume on the unthinned check plot averages only 1.5 cords per acre. Cordwood production on individual plots ranges from 0.0 to 24.2 cords per acre. The two most dense plots, each with over 6,000 trees per acre, produced no commercial wood. Merchantable volume increased as density decreased until a stocking of 436 trees per acre was reached, after which volume production declined as density declined. As age increases, the volume-density relationship will assume a more normal pattern. Differences in cordwood yield between plots of about the same number of trees per acre can be attributed to site variation.

Table 3. --Merchantable cubic-foot and cordwood production 14 years after treatment (17 years from seed)[1]

Block	Check		Clump		Single-tree	
	Density	Cords[2]	Density	Cords[2]	Density	Cords[2]
1	4,513	1.5	697	14.0	436	24.2
2	2,925	4.5	662	16.4	331	16.5
3	8,816	0.0	2,021	6.2	366	15.6
4	6,795	0.0	2,422	3.1	331	10.7
Mean	5,762	1.5	1,450	9.9	366	16.8

[1] Includes all trees 4.6 inches and larger at d. b. h., and a minimum top diameter of 4 inches outside bark.

[2] Standard cord of 92 cubic feet.

DISCUSSION

The height-density relationship illustrated in figure 2 implies that site index curves should be adjusted for density effect. If dense reproduction is not thinned early, site index estimates will be too low. In Block 1, for instance, total dominant height on the single-tree plot is 45 feet, but the check plot shows dominant height of 34 feet. While there is no actual difference in site potential between these plots, as estimated by soil measurement, the site index value for the unthinned plot is 19 feet below that for the thinned stand. If density is maintained within a range normally accepted in slash pine management, however, height growth apparently will not be affected enough to cause a serious problem. For example, a stand of 500 trees is only 2 feet taller than a stand of 1,500 (fig. 2).

This result emphasizes the need for early thinning in dense natural slash pine stands, especially when short rotations are involved. Assuming a rotation age of 25 years, the check treatment has only 8 more years in which to equal the economic status already gained by the clump and single-tree plots. This is hardly probable when one considers that most trees in these unthinned plots are in the 2-inch diameter class, and the average crown ratio of dominant trees is only 26 percent.

The 1951 thinning was done with a 2-man crew and a wheeled buggy saw. Approximately 4 crew-hours per acre were required to thin to clumps with an additional 1/2 crew-hour to thin to single trees. Although the buggy saw used in the thinning operation is seldom used today, other hand-operated brush saws are equally efficient on small areas. For large abandoned fields or site-prepared and broadcast-seeded areas, tractor-drawn rotary mowers or disk harrows would reduce manpower requirements. Regardless of the site or the method, it is highly important from both an economic and a physiological standpoint that the thinning be accomplished at an early age.

CONCLUSIONS

The results of this study show that height growth in slash pine is significantly reduced by stand density (trees per acre). Thinning dense stands at an early age will greatly increase height growth and merchantable volume for 20- to 25-year harvests. For a short pulpwood rotation, early precommercial thinning is imperative.

It is concluded that, for a dense, unthinned stand of natural slash pine, dominant height is not a true indicator of productive potential for a managed stand on the same site.

Some Chemical Properties of Forest Soils in the Virginia-Carolina Piedmont

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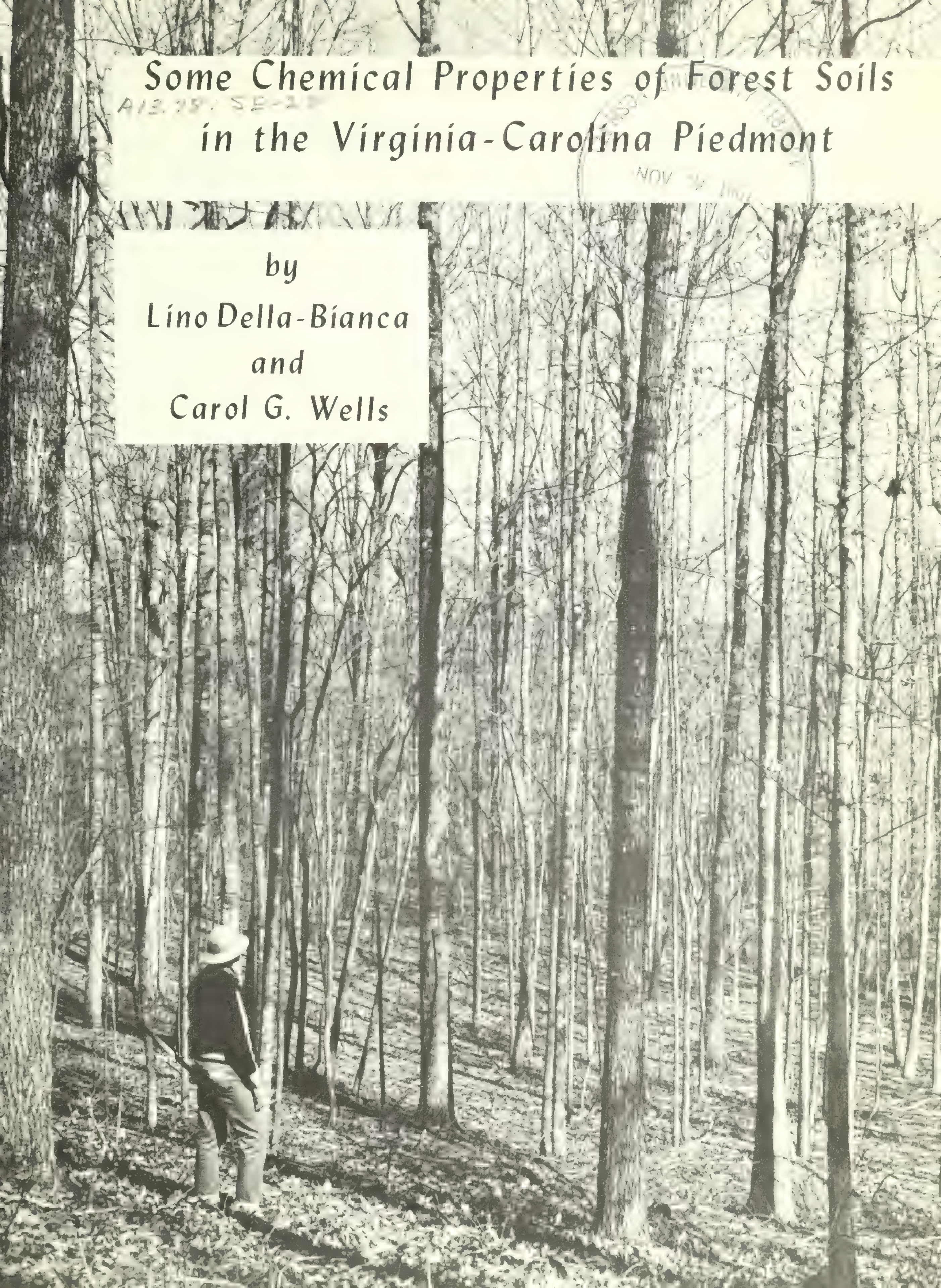
by

Lino Della-Bianca

and

Carol G. Wells



U. S. Forest Service Research Paper SE- 28

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Forest Service - U.S. Department of Agriculture
Southeastern Forest Experiment Station
Asheville, North Carolina

Cover photo: A well-stocked, second-growth, Piedmont timber stand.

Some Chemical Properties of Forest Soils in the Virginia-Carolina Piedmont

by

Lino Della-Bianca, Associate Silviculturist
and
Carol G. Wells, Soil Scientist

Upland hardwood and pine-hardwood forests cover more than 6 million acres of the Virginia-Carolina Piedmont. The acreage in hardwoods has been steadily increasing because of the successional trend toward the oak-hickory climax. However, relatively few studies have been made to determine the chemical properties of the associated forest soils. The information presented in this paper will increase our knowledge of the amount and distribution of several important chemical elements within the profile of a number of Piedmont hardwood and pine-hardwood forest soils.

Coile (1940), Metz (1954), and Wells and Metz (1963) determined the chemical properties of certain Piedmont forest soil types. In addition, the Southern Cooperative Series Bulletin 61 (Virginia Polytechnic Institute 1959) presented detailed chemical and physical properties for individual profiles of the Appling, Cecil, and Davidson series.

The soils included in the study reported here belong mostly to the red-yellow podzolic group, and represent seven of the eight parent material categories listed for the Piedmont Plateau upland (Lee 1955). The soil series are:

Appling
Cataula
Cecil
Chewacla
Colfax
Davidson
Durham
Enon
Georgeville
Goldston
Granville
Hayesville
Helena
Herndon
Hiwassee
Lloyd
Madison
Mecklenburg
Roanoke
Seneca
Starr
State
Tate
Tirzah
Wilkes
Worsham

Soil series were classified by the following soil scientists of the Soil Conservation Service, U. S. Department of Agriculture: Earl H. Brunger, Virginia; Charles L. Hunt, Charles S. Wilson, and E. O. Brewer, North Carolina; and Wallace J. Camp and Huger S. Byrd, South Carolina. Acknowledgment is made to Clemson University, Duke Power Company, Hardwood Research Council, and Duke University for assistance during phases of this research.

About 40 percent of the Piedmont soils have developed from acid crystalline rocks, such as granite, gneiss, and schist. These soils include the Cecil, Cataula, Appling, Durham, Colfax, Worsham, and Hayesville (a foothills soil) series. The Madison series contains much mica and is associated with quartz mica schist parent material.

Basic crystalline rocks, such as diorite, gabbro, diabase, and hornblende are parent material for the Davidson, Lloyd, and Mecklenburg series. Helena, Wilkes, and Enon soils developed from mixtures of acidic and basic crystalline materials which resulted from granite and gneiss formations cut by dikes of, or intruded by, basic rock.

Georgeville, Herndon, Tirzah, and Goldston soils are found over a large group of volcanic and sedimentary formations collectively known as "Carolina Slates." In the adjacent Triassic Basin, the Granville series has evolved from Triassic sandstones.

The Seneca, Starr, and Tate (a foothills soil) series, which are mixed-colluvium soils, occur locally.

In addition to the upland soils, small areas of stream-terrace soils include the State, Hiwassee, and Roanoke series. The Chewacla series developed from alluvial sediments.

Methods

The soils used for this study were sampled in 153 well-stocked, second-growth, upland hardwood or pine-hardwood stands in the Piedmont (fig. 1). Study plots ranged from 1/5 to 1/2 acre in size, and were uniform with respect to soil type, litter cover, topography, aspect, and degree of slope (Della-Bianca and Olson 1961). Only well-developed stands 30 to 100 years old that had not been burned, grazed, or cut over were sampled.

Four soil sample pits were located on each plot and soil samples were taken from each horizon for analysis (fig. 2). Organic matter content was determined by the wet combustion method (Chesnin 1950); magnesium, potassium, and calcium were extracted with neutral normal ammonium acetate and analyzed by flame spectrophotometer; phosphorus was analyzed by the Truog method; and pH was determined by glass electrode.

Because this research is a phase of an earlier soil-site study (Della-Bianca and Olson 1961), the soil series distribution of these sample plots was determined by the initial study, in which timber stand and visual soil characteristics governed plot selection. No attempt was made to sample individual soil series with equal intensity. Generally, the sampling intensity by soil series paralleled the areal distribution percentages of the various soil series over the entire portion of the Virginia-Carolina Piedmont studied.

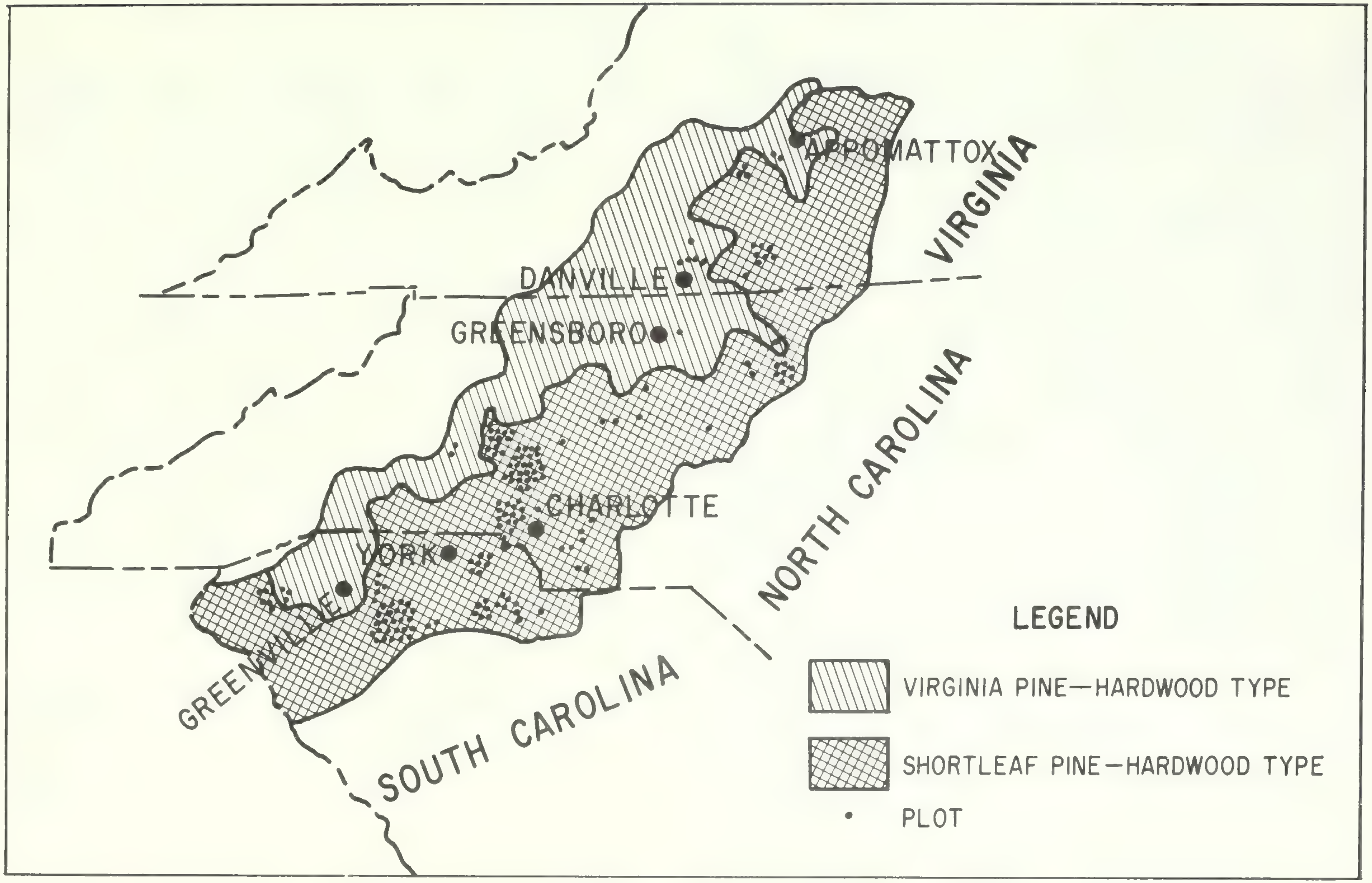

Figure 1.--Distribution of soil-site plots in the Virginia-Carolina Piedmont.

Figure 2.--Sampling a Piedmont forest soil profile in a mixed hardwood stand.

Results and Discussion

Nine of the 26 soil series sampled were represented by five or more plots (table 1) and were used for statistical analyses. The Cecil series was found on 52 plots and made possible comparisons between soil types. Chemical data for the remaining 17 series, which were lightly sampled, appear in the Appendix (tables 4 and 5) as means or individual values for soil types.

Because the calcium concentrations (table 1) varied more between means than did potassium, magnesium, or phosphorus, it was selected for detailed statistical analyses in the A_1 and B_2 horizons. These particular horizons were chosen because: the A_1 horizon reflects the influence of the overlying forest floor, and in the Piedmont, as elsewhere, biotic influences are greatest in the A_1 horizon; chemical characteristics in the B_2 horizon are strongly influenced by the underlying parent material and leachate from above.

The analysis of variance for calcium levels showed highly significant differences existed between soil series and between soil horizons. Multiple-range tests were made to evaluate further the significance of differences between soil series.

In the A_1 horizon, the Davidson series, with 2,460 parts per million of calcium, contained significantly more calcium than the Appling, Cataula, Georgeville, or Cecil series; in addition, the Lloyd series had significantly more calcium than the Appling.

Calcium comparisons for the B_2 horizon showed that the Mecklenburg series had significantly more calcium than the Georgeville, Cecil, Starr, Appling, or Lloyd series. Similarly, the Enon series contained more calcium than the Georgeville or Cecil series.

Table 1. --Chemical properties of several soil series in hardwood and pine-hardwood upland forests of the Virginia-Carolina Piedmont

Soil series	Plots	Thickness	pH	Organic matter	K	Ca	Mg	P
	Number	Inches		Percent	- - -	Parts per million	- - -	
				A_1 SOIL HORIZON				
Appling	10	1.7	5.0	10.2	162	801	140	14
Cataula	5	1.5	5.0	11.4	179	1,022	212	11
Cecil	52	1.7	5.3	12.1	199	1,162	232	16
Davidson	9	1.1	6.0	15.3	274	2,460	325	13
Enon	5	3.0	5.7	8.1	135	1,532	205	11
Georgeville	5	1.0	4.7	21.1	218	1,118	183	20
Lloyd	17	2.1	5.7	12.0	200	1,754	268	14
Mecklenburg	5	2.6	5.7	11.3	197	1,368	227	13
Starr	6	1.3	5.4	16.0	262	1,338	307	22
				A_2 SOIL HORIZON				
Appling	10	7.3	5.2	1.3	55	117	53	3
Cataula	5	5.6	5.1	1.9	69	274	128	3
Cecil	52	5.5	5.3	2.1	84	168	79	4
Davidson	9	4.3	5.8	3.6	133	669	156	4
Enon	5	6.5	5.8	1.3	68	215	90	2
Georgeville	5	3.9	4.7	2.8	70	75	102	4
Lloyd	16	4.7	5.5	2.8	92	320	116	4
Mecklenburg	5	7.4	5.5	2.0	70	290	151	3
Starr	6	5.0	5.1	2.6	117	78	154	4
				B_1 SOIL HORIZON				
Appling	10	5.3	5.0	--	63	112	91	1
Cataula	5	3.9	5.2	--	70	199	150	2
Cecil	52	4.2	5.1	--	75	100	104	1
Davidson	9	4.9	5.6	--	87	151	99	1
Enon	5	6.0	5.5	--	57	217	100	1
Georgeville	5	4.0	4.9	--	47	57	72	1
Lloyd	17	5.3	5.3	--	74	180	131	1
Mecklenburg	5	9.2	5.3	--	47	243	151	1
Starr	5	6.7	4.9	--	79	105	93	1
				B_2 SOIL HORIZON				
Appling	10	--	5.2	--	89	198	156	1
Cataula	5	--	5.1	--	92	215	228	1
Cecil	52	--	5.1	--	104	129	186	1
Davidson	9	--	5.5	--	97	271	195	1
Enon	5	--	5.2	--	47	334	154	1
Georgeville	5	--	4.9	--	44	75	149	1
Lloyd	17	--	5.2	--	95	205	183	1
Mecklenburg	5	--	5.2	--	51	414	249	1
Starr	6	--	5.2	--	90	161	125	1

Other comparisons, by soil series, of calcium contents shown in table 1, were not significantly different for either the A_1 or B_2 horizon.

Generally, the soil series studied showed that the A_1 horizon contained the heaviest concentration of nutrients. Calcium levels decreased sharply from the A_1 (maximum level) to the A_2 horizon, generally decreased from the A_2 to the B_1, and then increased slightly from the B_1 to the B_2 horizon. Other elements were distributed between soil horizons in essentially the same pattern as calcium.

The mean values shown in table 1 for organic matter, potassium, calcium, magnesium, and phosphorus were expanded through standard computational procedures involving bulk density and horizon thickness into pounds per acre (table 2). Of the nine soil series, the Georgeville contained the least total nutrients (table 2), primarily because of shallow soil and low nutrient concentrations in the A_2 and B_1 soil horizons (table 1). Furthermore, nutrient levels in the B_2 horizon (table 1) indicated that the "Carolina Slate" parent material of the Georgeville series was a poor source of nutrients.

The Cecil soil series is the most widespread series in the Virginia-Carolina Piedmont. Logically, then, the near-random sample of forest stands would be expected to yield a high percentage of soil-site plots in the Cecil series--which happened in this case. Because of the large number of plots (52) included in this series, it was possible to stratify them by soil types as follows: 30 plots were Cecil sandy loam, 3 were Cecil loam, and 19 were Cecil sandy clay loam (table 3).

Table 2.--Pounds per acre of nutrients ($A_1 + A_2 + B_1$ horizon), organic matter ($A_1 + A_2$ horizon), and soil thickness ($A_1 + A_2 + B_1$ horizon) for hardwood and pine-hardwood upland forests of the Virginia-Carolina Piedmont

Soil series	Plots[1]	Thickness	Organic Matter	K	Ca	Mg	P
	Number	Inches	Pounds per acre				
Appling	10	14.3	74,918	314	829	351	15
Cataula	5	11.0	72,358	270	1,083	486	12
Cecil	52	11.4	83,280	324	885	369	14
Davidson	9	10.3	71,292	331	1,469	385	8
Enon	5	15.5	79,450	345	1,898	526	13
Georgeville	5	8.9	71,836	176	365	236	10
Lloyd	17	12.1	89,195	327	1,479	480	13
Mecklenburg	5	19.2	91,483	353	1,851	802	15
Starr	6	13.0	84,662	410	720	506	14

[1] Average bulk density values for computing pounds per acre were determined for each horizon by soil series.

Table 3. --Chemical properties of Cecil soil types in hardwood and pine-hardwood upland forests of the Virginia-Carolina Piedmont

Soil type[1]	Plots	Statistical variable	Thickness	pH	Organic matter	K	Ca	Mg	P
					A_1 SOIL HORIZON				
	Number		Inches		Percent	- - - - Parts per million - - - -			
Sandy loam	30	Range	0.5-6.5	3.9-6.8	4.6-25.5	96-277	140-3,590	65-525	4-33
		Mean	1.9	5.2	10.5	163	1,010	184	13
Loam	3	Range	0.8-1.9	3.9-6.1	13.2-20.8	224-280	180-3,240	125-540	16-27
		Mean	1.2	5.4	16.6	257	1,900	355	20
Sandy clay loam	19	Range	0.4-3.6	4.1-6.2	7.1-21.5	148-475	240-2,580	110-600	5-50
		Mean	1.4	5.3	13.8	246	1,285	290	19
Combined	52	Range	0.4-6.5	3.9-6.8	4.6-25.5	96-475	140-3,590	65-600	4-50
		Mean	1.7	5.3	12.1	199	1,162	232	16
					A_2 SOIL HORIZON				
Sandy loam	30	Range	3.0-12.6	4.8-6.1	0.3-3.6	28-167	10-610	12-140	1-8
		Mean	5.9	5.3	1.9	72	146	66	4
Loam	3	Range	2.3-5.3	4.7-6.3	1.4-5.1	46-175	2-1,090	1-250	4-8
		Mean	4.1	5.7	3.4	115	531	127	6
Sandy clay loam	19	Range	2.5-13.0	4.8-5.7	1.2-3.4	47-159	10-420	7-185	1-7
		Mean	5.3	5.3	2.2	101	148	95	4
Combined	52	Range	2.3-13.0	4.7-6.3	0.3-5.1	28-175	2-1,090	1-250	1-8
		Mean	5.5	5.3	2.1	84	168	79	4
					B_1 SOIL HORIZON				
Sandy loam	30	Range	2.4-7.6	4.8-5.6	--	12-105	15-300	11-225	1-4
		Mean	4.0	5.1	--	66	91	97	1
Loam	3	Range	2.1-3.7	4.8-5.5	--	58-104	10-370	28-145	1-2
		Mean	2.9	5.2	--	74	168	88	1
Sandy clay loam	19	Range	2.4-9.9	4.8-5.5	--	39-164	15-365	35-175	1-2
		Mean	4.7	5.1	--	90	102	117	1
Combined	52	Range	2.1-9.9	4.8-5.6	--	12-164	10-370	11-225	1-4
		Mean	4.2	5.1	--	75	100	104	1
					B_2 SOIL HORIZON				
Sandy loam	30	Range	--	4.7-5.4	--	12-185	18-650	102-375	1-1
		Mean	--	5.1	--	99	136	183	1
Loam	3	Range	--	4.9-5.4	--	66-128	16-182	116-255	1-2
		Mean	--	5.2	--	105	106	179	1
Sandy clay loam	19	Range	--	4.8-5.4	--	45-202	18-518	90-290	1-2
		Mean	--	5.1	--	111	121	193	1
Combined	52	Range	--	4.7-5.4	--	12-202	16-650	90-375	1-2
		Mean	--	5.1	--	104	129	186	1

[1] Basis: Soil texture analysis of the A_2 soil horizon.

Although only three plots were classified as Cecil loams, the range of several chemical properties spanned the entire range shown for the 52 Cecil plots. For example, in the A_2 horizon, calcium ranged from 2 to 1,090 parts per million; pH ranged from 4.7 to 6.3; and magnesium ranged from 1 to 250 parts per million. Similarly, several chemical properties shown for the Cecil sandy loam plots include the extreme values of the variable sampled. Considering these large overlaps in chemical properties when comparing soil types, the soil type scheme is not accurate enough for evaluating nutrient levels between Cecil soils.

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APPENDIX

Table 4.--Chemical properties for some soil types within series in hardwood and pine-hardwood upland forests of the Virginia-Carolina Piedmont

Soil type[1]	Plots	Thickness	pH	Organic matter	K	Ca	Mg	P
	Number	Inches		Percent	- - -	Parts per million	- - -	
APPLING SOIL SERIES								
A_1 SOIL HORIZON								
Sandy loam	8	1.8	4.9	10.0	147	579	94	12
Sandy clay loam	2	1.0	5.6	11.0	275	1,690	320	21
A_2 SOIL HORIZON								
Sandy loam	8	7.7	5.0	1.0	44	61	32	3
Sandy clay loam	2	5.6	5.6	2.5	102	344	138	4
B_1 SOIL HORIZON								
Sandy loam	8	5.4	5.0	--	59	96	86	1
Sandy clay loam	2	4.8	5.2	--	82	178	110	2
B_2 SOIL HORIZON								
Sandy loam	8	--	5.2	--	81	189	144	1
Sandy clay loam	2	--	5.2	--	121	236	206	1
CATAULA SOIL SERIES								
A_1 SOIL HORIZON								
Sandy loam	3	2.0	4.8	7.8	145	443	80	7
Loam	1	1.4	6.1	14.2	252	2,860	605	16
Sandy clay loam	1	0.2	4.6	19.5	210	920	215	20
A_2 SOIL HORIZON								
Sandy loam	3	8.3	4.9	1.3	41	47	49	2
Loam	1	1.6	6.0	4.1	138	1,070	355	4
Sandy clay loam	1	1.6	4.8	1.7	85	160	140	4
B_1 SOIL HORIZON								
Sandy loam	3	3.9	5.0	--	53	60	93	2
Loam	1	2.8	5.9	--	129	675	310	2
Sandy clay loam	1	5.0	5.2	--	63	140	160	2
B_2 SOIL HORIZON								
Sandy loam	3	--	5.0	--	79	93	143	1
Loam	1	--	5.5	--	157	540	330	1
Sandy clay loam	1	--	5.1	--	65	256	380	1

[1] Basis: Soil texture analysis of the A_2 horizon.

Table 4. --Chemical properties for some soil types within series in hardwood and pine-hardwood upland forests of the Virginia-Carolina Piedmont (continued)

CHEWACLA SOIL SERIES

A_1 SOIL HORIZON

Soil type[1]	Plots	Thickness	pH	Organic matter	K	Ca	Mg	P
	Number	Inches		Percent	- - -	Parts per million	- - -	
Loam	1	1.0	5.9	14.4	178	3,220	410	49
Silty clay loam	1	1.0	5.7	15.0	216	4,360	680	54
A_2 SOIL HORIZON								
Loam	1	8.3	5.4	1.3	44	570	130	9
Silty clay loam	1	6.2	5.1	2.6	55	670	205	4
B_1 SOIL HORIZON								
Loam	1	--	--	--	--	--	--	--
Silty clay loam	1	6.3	5.2	--	23	590	180	4
B_2 SOIL HORIZON								
Loam	1	--	5.3	--	37	622	123	4
Silty clay loam	1	--	5.4	--	26	800	280	2

DAVIDSON SOIL SERIES

A_1 SOIL HORIZON

Soil type[1]	Plots	Thickness	pH	Organic matter	K	Ca	Mg	P
Sandy clay loam	1	0.9	5.6	12.1	155	2,210	270	16
Loam	1	1.0	6.7	14.6	302	3,130	455	14
Clay loam	6	1.1	6.1	14.0	262	2,457	310	11
Clay	1	1.2	5.3	27.0	434	2,060	340	21
A_2 SOIL HORIZON								
Sandy clay loam	1	2.2	6.0	1.9	104	850	190	3
Loam	1	5.2	6.2	3.1	206	900	190	6
Clay loam	6	4.4	5.8	3.8	129	687	144	4
Clay	1	4.4	5.0	4.7	119	150	160	2
B_1 SOIL HORIZON								
Sandy clay loam	1	3.7	5.7	--	120	785	45	1
Loam	1	4.3	5.8	--	58	25	30	2
Clay loam	6	5.3	5.6	--	85	78	102	1
Clay	1	3.8	5.1	--	90	80	200	1
B_2 SOIL HORIZON								
Sandy clay loam	1	--	5.3	--	56	810	310	1
Loam	1	--	5.4	--	139	370	235	1
Clay loam	6	--	5.6	--	102	205	165	1
Clay	1	--	5.1	--	62	32	220	2

[1] Basis: Soil texture analysis of the A_2 horizon.

Table 4. --Chemical properties for some soil types within series in hardwood and pine-hardwood upland forests of the Virginia-Carolina Piedmont (continued)

Soil type[1]	Plots	Thickness	pH	Organic matter	K	Ca	Mg	P
	Number	Inches		Percent	- - - Parts per million - - -			
DURHAM SOIL SERIES								
A_1 SOIL HORIZON								
Sandy loam	2	4.0	5.6	5.0	84	665	82	8
Sandy clay loam	2	5.7	5.3	7.7	148	755	138	10
A_2 SOIL HORIZON								
Sandy loam	2	6.6	5.6	0.6	36	20	61	2
Sandy clay loam	2	5.5	5.0	1.2	82	60	40	2
B_1 SOIL HORIZON								
Sandy loam	2	5.1	5.2	--	44	138	80	1
Sandy clay loam	2	5.8	5.0	--	68	28	47	1
B_2 SOIL HORIZON								
Sandy loam	2	--	4.9	--	50	193	120	2
Sandy clay loam	2	--	4.8	--	71	19	48	1
ENON SOIL SERIES								
A_1 SOIL HORIZON								
Sandy loam	3	3.0	5.7	8.8	124	1,880	227	13
Sandy clay loam	2	3.1	5.8	7.0	152	1,010	178	9
A_2 SOIL HORIZON								
Sandy loam	3	5.9	5.9	1.4	54	283	65	3
Sandy clay loam	2	7.5	5.6	1.2	88	113	128	2
B_1 SOIL HORIZON								
Sandy loam	3	5.4	5.6	--	41	237	79	1
Sandy clay loam	2	7.1	5.4	--	82	188	131	1
B_2 SOIL HORIZON								
Sandy loam	3	--	5.1	--	38	383	167	1
Sandy clay loam	2	--	5.2	--	60	260	135	1

[1] Basis: Soil texture analysis of the A_2 horizon.

Table 4. --Chemical properties for some soil types within series in hardwood and pine-hardwood upland forests of the Virginia-Carolina Piedmont (continued)

Soil type[1]	Plots	Thickness	pH	Organic matter	K	Ca	Mg	P
GEORGEVILLE SOIL SERIES								
A_1 SOIL HORIZON								
	Number	Inches		Percent	- - -	Parts per million	- - -	
Loam	1	0.8	5.1	12.1	173	1,240	210	16
Clay loam	1	1.2	4.7	13.6	215	610	100	16
Silt loam	1	1.0	4.3	16.2	162	320	105	12
Silty clay loam	2	1.0	4.8	31.8	270	1,710	250	28
A_2 SOIL HORIZON								
Loam	1	3.7	4.8	2.6	60	115	94	4
Clay loam	1	4.4	4.9	2.6	60	20	38	3
Silt loam	1	2.5	4.5	3.3	62	50	28	4
Silty clay loam	2	4.5	4.8	2.7	84	96	176	4
B_1 SOIL HORIZON								
Loam	1	5.9	4.9	--	30	130	132	1
Clay loam	1	4.6	4.9	--	49	50	67	1
Silt loam	1	3.4	4.7	--	33	28	38	2
Silty clay loam	2	3.0	4.9	--	62	38	62	1
B_2 SOIL HORIZON								
Loam	1	--	4.7	--	34	210	370	1
Clay loam	1	--	5.3	--	46	46	77	1
Silt loam	1	--	4.9	--	40	18	114	1
Silty clay loam	2	--	4.9	--	50	50	92	1
GOLDSTON SOIL SERIES								
A_1 SOIL HORIZON								
Clay loam	1	0.9	5.1	18.3	233	1,880	380	24
Silt loam	2	0.9	5.0	27.8	235	1,725	275	22
A_2 SOIL HORIZON								
Clay loam	1	5.5	4.9	2.6	98	138	88	6
Silt loam	2	3.0	4.8	3.5	86	182	65	6
B_1 SOIL HORIZON								
Clay loam	1	2.5	4.9	--	80	48	13	1
Silt loam	2	4.9	4.8	--	34	85	109	2
B_2 SOIL HORIZON								
Clay loam	1	--	5.0	--	86	50	195	1
Silt loam	2	--	4.6	--	26	97	119	1

[1] Basis: Soil texture analysis of the A_2 horizon.

Table 4. --Chemical properties for some soil types within series in hardwood and pine-hardwood upland forests of the Virginia-Carolina Piedmont (continued)

HELENA SOIL SERIES

A_1 SOIL HORIZON

Soil type[1]	Plots	Thickness	pH	Organic matter	K	Ca	Mg	P
	Number	Inches		Percent	- - - Parts per million - - -			
Sandy loam	1	2.8	5.7	7.9	104	1,360	240	20
Sandy clay loam	1	3.6	6.0	9.6	172	1,490	215	8
A_2 SOIL HORIZON								
Sandy loam	1	2.2	5.3	1.2	19	110	45	2
Sandy clay loam	1	4.0	5.6	1.1	152	160	64	1
B_1 SOIL HORIZON								
Sandy loam	1	3.0	4.6	--	13	130	72	1
Sandy clay loam	1	3.3	5.4	--	41	100	100	1
B_2 SOIL HORIZON								
Sandy loam	1	--	4.5	--	15	318	93	1
Sandy clay loam	1	--	5.2	--	40	84	132	1
LLOYD SOIL SERIES								
A_1 SOIL HORIZON								
Sandy loam	2	1.2	5.8	11.5	194	1,280	248	12
Sandy clay loam	6	2.6	5.4	10.3	172	985	166	10
Loam	6	1.2	6.0	16.2	244	2,885	381	20
Clay loam	3	3.5	5.6	7.5	173	1,347	258	11
A_2 SOIL HORIZON								
Sandy loam	2	5.6	5.4	1.8	65	105	86	2
Sandy clay loam	6	5.4	5.3	2.5	85	169	76	2
Loam	6	4.3	5.8	3.3	99	462	152	5
Clay loam	3	3.0	5.6	2.9	122	560	155	5
B_1 SOIL HORIZON								
Sandy loam	2	3.8	5.1	--	68	98	127	1
Sandy clay loam	6	6.6	5.3	--	76	115	113	2
Loam	6	5.0	5.5	--	77	258	149	2
Clay loam	3	4.3	5.3	--	69	210	135	2
B_2 SOIL HORIZON								
Sandy loam	2	--	5.0	--	99	63	235	1
Sandy clay loam	6	--	5.3	--	87	117	135	1
Loam	6	--	5.2	--	102	349	211	1
Clay loam	3	--	5.1	--	94	190	185	1

[1] Basis: Soil texture analysis of the A_2 horizon.

Table 4.--Chemical properties for some soil types within series in hardwood and pine-hardwood upland forests of the Virginia-Carolina Piedmont (continued)

MECKLENBURG SOIL SERIES

A_1 SOIL HORIZON

Soil type[1]	Plots	Thickness	pH	Organic matter	K	Ca	Mg	P
	Number	Inches		Percent	- - -	Parts per million	- - -	
Sandy loam	1	1.1	5.7	14.2	228	1,830	260	21
Loam	1	1.9	6.6	7.6	207	2,940	340	13
Sandy clay loam	2	4.0	5.9	7.8	158	640	210	8
Silt loam	1	1.9	4.4	19.0	234	790	115	14
A_2 SOIL HORIZON								
Sandy loam	1	5.9	5.6	1.5	77	32	225	4
Loam	1	6.3	6.1	2.1	127	945	300	4
Sandy clay loam	2	9.4	5.6	1.6	60	228	112	2
Silt loam	1	5.7	4.7	3.1	28	20	7	3
B_1 SOIL HORIZON								
Sandy loam	1	4.5	5.1	--	47	380	375	1
Loam	1	7.8	5.5	--	65	530	142	2
Sandy clay loam	2	14.6	5.6	--	54	146	103	1
Silt loam	1	4.6	4.7	--	14	10	33	2
B_2 SOIL HORIZON								
Sandy loam	1	--	5.0	--	45	820	600	1
Loam	1	--	5.4	--	79	850	160	1
Sandy clay loam	2	--	5.3	--	55	189	181	1
Silt loam	1	--	4.8	--	21	22	125	1
SENECA SOIL SERIES								
A_1 SOIL HORIZON								
Loam	1	1.3	4.6	20.1	293	630	355	18
Sandy clay loam	1	2.2	5.6	7.2	154	1,080	260	11
A_2 SOIL HORIZON								
Loam	1	9.8	5.2	2.8	101	60	80	5
Sandy clay loam	1	19.2	5.1	1.4	65	60	18	1
B_1 SOIL HORIZON								
Loam	1	9.3	5.3	--	75	20	120	2
Sandy clay loam	1	12.5	5.3	--	79	90	58	1
B_2 SOIL HORIZON								
Loam	1	--	5.5	--	81	24	127	2
Sandy clay loam	1	--	5.5	--	81	104	80	1

[1] Basis: Soil texture analysis of the A_2 horizon.

Table 4. --Chemical properties for some soil types within series in hardwood and pine-hardwood upland forests of the Virginia-Carolina Piedmont (continued)

STARR SOIL SERIES

Soil type[1]	Plots	Thickness	pH	Organic matter	K	Ca	Mg	P
	Number	Inches		Percent	- - - Parts per million - - -			
A_1 SOIL HORIZON								
Loam	2	1.0	6.0	16.0	282	2,180	362	26
Sandy clay loam	1	1.7	6.0	9.5	212	2,040	230	20
Clay loam	3	1.4	4.7	18.1	264	543	295	20
A_2 SOIL HORIZON								
Loam	2	4.8	5.6	3.8	166	94	272	5
Sandy clay loam	1	4.2	5.3	1.4	71	34	120	2
Clay loam	3	5.4	4.8	2.3	99	83	86	4
B_1 SOIL HORIZON								
Loam	2	6.6	4.8	--	106	140	122	1
Sandy clay loam	1	6.9	5.1	--	51	205	76	1
Clay loam	2	6.8	5.0	--	66	20	71	1
B_2 SOIL HORIZON								
Loam	2	--	5.0	--	90	145	109	1
Sandy clay loam	1	--	5.3	--	42	240	70	1
Clay loam	3	--	5.3	--	105	145	154	1

[1] Basis: Soil texture analysis of the A_2 horizon.

Table 5. --Some chemical properties of individual soil types in hardwood and pine-hardwood upland forests of the Virginia-Carolina Piedmont[1]

Soil type[2]	Soil horizon	Thickness	pH	Organic matter	K	Ca	Mg	P
		Inches		Percent	- - - Parts per million - - -			
Colfax sandy loam	A_1	3.4	4.0	9.2	67	160	65	11
	A_2	9.4	4.9	0.7	12	20	13	2
	B_1	6.0	4.8	--	10	20	23	1
	B_2	--	4.7	--	11	18	44	1
Granville sandy loam	A_1	5.1	5.4	6.0	89	580	100	8
	A_2	7.0	5.0	0.6	38	74	30	1
	B_1	7.4	4.8	--	37	30	50	1
	B_2	--	5.0	--	46	40	80	1
Hayesville clay loam	A_1	0.5	4.0	25.6	240	1,400	200	32
	A_2	1.8	4.4	4.5	99	100	60	5
	B_1	2.2	4.6	--	80	50	55	2
	B_2	--	4.9	--	101	78	112	1
Herndon silt loam	A_1	0.8	4.9	14.8	207	1,615	220	23
	A_2	4.2	4.7	2.3	42	59	41	4
	B_1	5.2	4.8	--	30	87	69	1
	B_2	--	5.0	--	28	232	144	1

[1] Values are for individual plots, except for the Herndon, Madison, and Mixed-Colluvium types, represented by 2, 3, and 4 plots, respectively.

[2] Basis: Soil texture analysis of the A_2 horizon.

Table 5. --Some chemical properties of individual soil types in hardwood and pine-hardwood upland forests of the Virginia-Carolina Piedmont[1] (continued)

Soil type[2]	Soil horizon	Thickness	pH	Organic matter	K	Ca	Mg	P
		Inches		Percent	- - - Parts per million - - -			
Hiwassee	A_1	0.2	5.6	15.2	198	2,700	370	33
clay loam	A_2	2.4	4.8	3.6	100	460	200	7
	B_1	1.9	5.0	--	82	450	180	2
	B_2	--	5.2	--	92	470	225	2
Madison	A_1	0.9	4.7	20.4	252	1,257	327	28
sandy clay loam	A_2	2.8	4.8	2.3	95	121	80	6
	B_1	3.0	5.0	--	97	80	141	2
	B_2	--	5.2	--	133	100	210	3
Mixed-Colluvium	A_1	3.3	5.3	5.4	100	825	252	8
sandy loam	A_2	8.8	5.1	0.9	40	296	183	2
	B_1	14.5	5.2	--	22	242	122	2
	B_2	--	5.1	--	29	347	139	2
Roanoke	A_1	1.3	4.8	7.0	92	500	140	10
sandy loam	A_2	8.9	5.1	1.1	46	16	66	3
	B_1	6.6	4.8	--	48	200	265	1
	B_2	--	4.6	--	72	352	700	1
State	A_1	6.4	6.4	4.2	142	1,440	245	13
sandy loam	A_2	7.5	5.0	0.4	30	160	73	4
	B_1	15.3	4.7	--	19	155	65	1
	B_2	--	5.2	--	13	230	85	1
Tate	A_1	0.2	5.0	17.0	264	1,960	300	23
loam	A_2	4.8	5.3	4.7	145	500	155	8
	B_1	3.1	5.0	--	101	170	100	3
	B_2	--	5.0	--	83	78	80	1
Tirzah	A_1	0.4	5.4	21.3	300	3,020	250	20
clay loam	A_2	2.0	5.6	4.6	136	860	175	6
	B_1	6.6	5.7	--	110	50	145	1
	B_2	--	5.6	--	79	420	87	1
Wilkes	A_1	2.1	5.5	6.7	102	780	225	28
sandy loam	A_2	9.4	5.7	1.1	60	182	175	8
	B_1	5.0	5.5	--	100	155	180	1
	B_2	--	5.3	--	190	470	315	1
Worsham	A_1	5.2	6.0	5.6	94	1,040	290	10
sandy loam	A_2	5.0	5.4	1.3	32	178	108	1
	B_1	4.6	5.4	--	15	175	80	2
	B_2	--	5.4	--	17	232	310	1

---

[1] Values are for individual plots, except for the Herndon, Madison, and Mixed-Colluvium types, represented by 2, 3, and 4 plots, respectively.

[2] Basis: Soil texture analysis of the A_2 horizon.

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Meteorological Conditions of the Hellgate Fire

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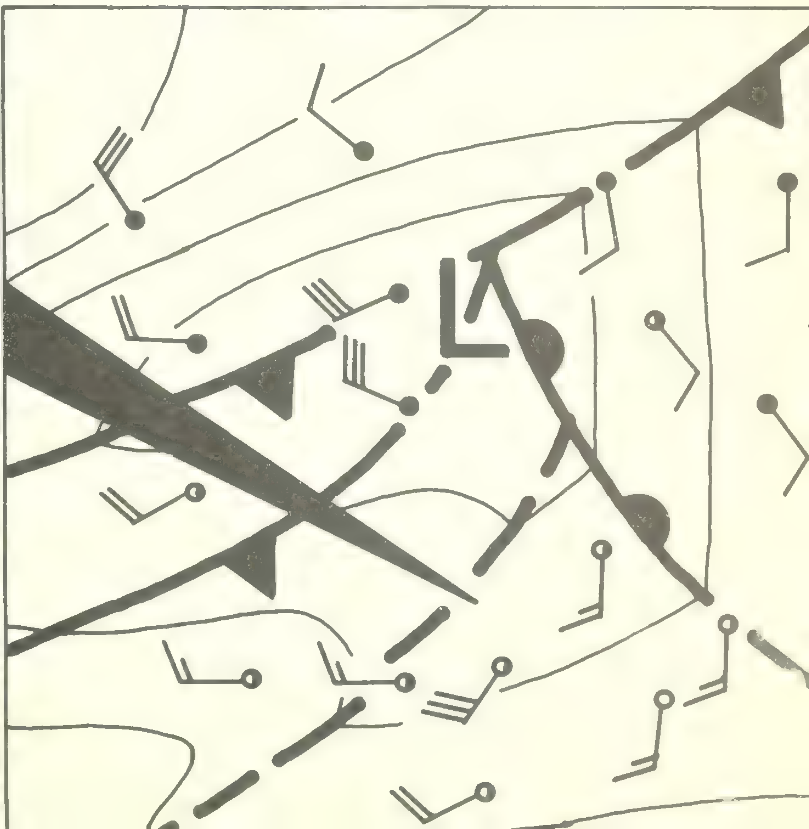

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Southeastern Forest Experiment Station - Asheville, North Carolina
U.S. Department of Agriculture - Forest Service

Meteorological Conditions of the Hellgate Fire

by

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INTRODUCTION

The Hellgate Fire occurred in the Pedlar District of the George Washington National Forest, beginning in the early afternoon of Easter Sunday, April 18, 1965, at a point 4½ miles south-southwest of the business district of Buena Vista, Virginia. By the time it was controlled early the next morning, 2,163 acres had been burned, representing $100,000 in growth loss and timber destroyed. Cost of fighting the fire was over $20,000.

The name of the fire is taken from Hellgate Ridge, a feature of a portion of the area burned. The topography of the area is steep, with slopes of 70 percent or more and elevations ranging from 980 to 2,432 feet (fig. 1). The forest cover was primarily oak and pine with heavy litter and slash at the surface.

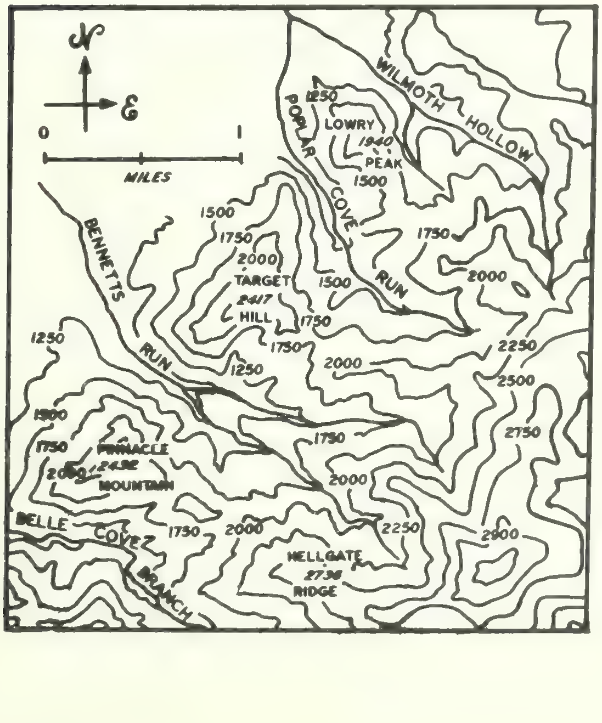

Figure 1.--Topography of the area burned by the Hellgate Fire. Contours are drawn for each 250 feet.

The fire is of special interest because of the rapid rate of spread early in its life history, when it was characterized by running, crowning, spotting, and the generation of fire whirlwinds. It is the purpose of this paper to describe the meteorological conditions that were present and to suggest how they may have contributed to the fire's behavior. The study covers the period from 1300 to 1600 EST.

DESCRIPTION OF THE FIRE

Smoke was first detected at 1335 EST at an elevation of 1,200 feet, about 100 feet northeast of a pipeline which follows the drainage feature called Bennett's Run (fig. 2). Five minutes later, at 1340 EST, smoke was reported "lying low" above the creek in Bennett's Run. It was "lying in" on the Pinnacle Mountain side to the southwest, and had progressed about 100 feet up the Target Hill side to the northeast. Wind was reported to be "blowing hard" at this time (1).

Rapid spread of the fire began at 1350 EST and continued to about 1500 EST. Spreading occurred in several directions, but with the greatest spread to the east.

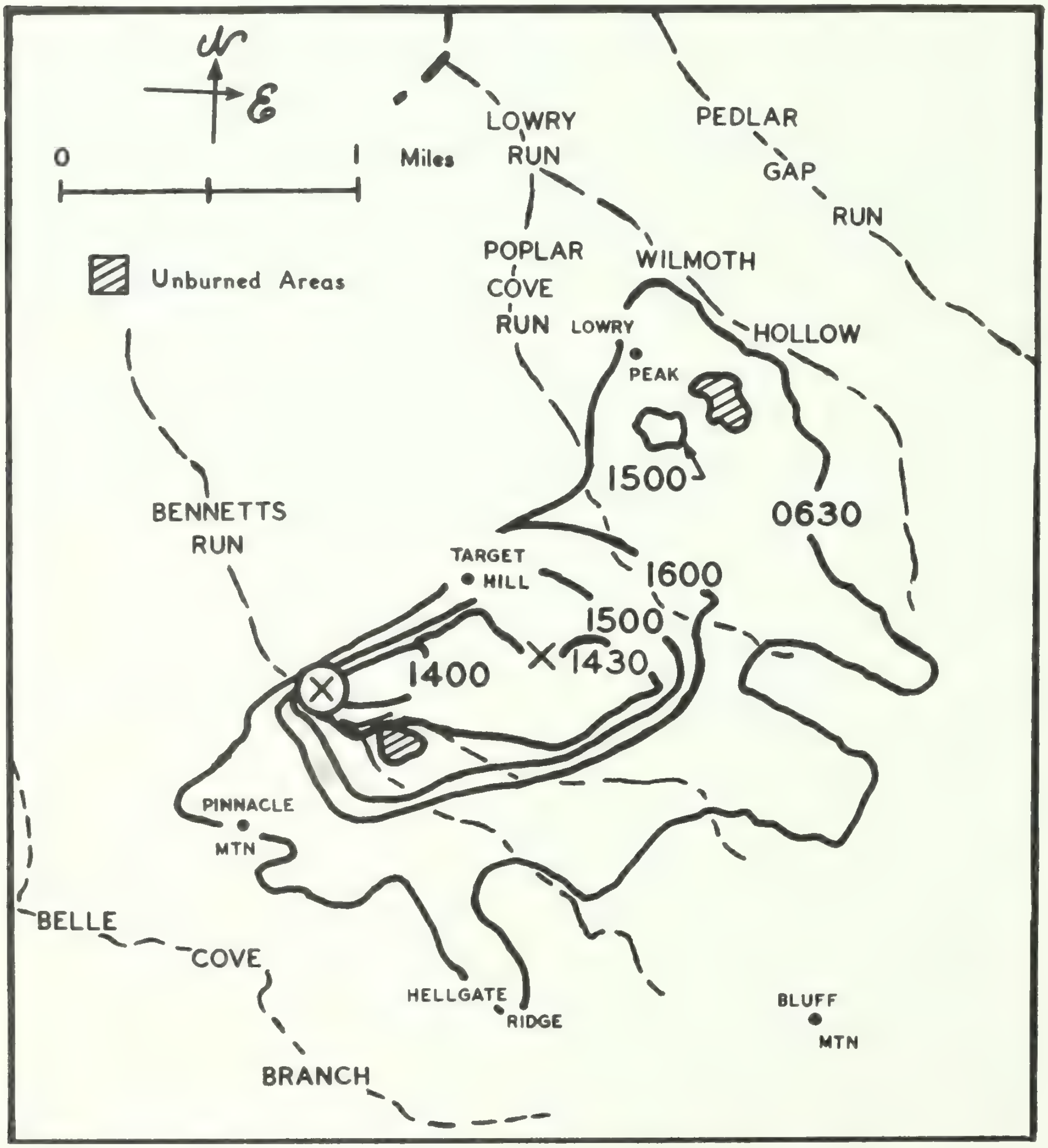

Figure 2. --Fire perimeters for 1400, 1430, 1500, and 1600 EST on the 18th, and the final fire perimeter at 0630 EST on the 19th. Origin point of the fire at 1335 EST is shown by the encircled "X." The shaded areas were not burned.

Spread to the east reached a maximum rate of 110 chains (7,260 feet) per hour during the period from 1400 to 1430 EST. Efforts to hold the fire at a point a little less than a mile east of the origin point, indicated by the open "X" in figure 2, were abandoned during this time. The fire continued to spread east and northeast, but at a somewhat lesser rate, reaching Poplar Cove Run shortly after 1500 EST. Many spot fires were generated in which twigs $\frac{1}{4}$ by 3 inches were dropped. Spotting occurred as far as 45 chains (2,970 feet) in advance of the fire front. Attempts to hold the fire at Poplar Cove Run failed when spotting occurred over the line onto the side of Lowry Peak to the northeast. This spot fire is indicated by the small, isolated 1500 EST fire perimeter in figure 2.

The fire spread southward, also. Attempts to keep the fire north of the pipeline in Bennett's Run failed, despite the efforts of a Forest Service pumper and the Buena Vista Fire Department pumper. Fire crews reported that a shift in the wind about 1430 EST caused the fire to cross the pipeline and to spread up Pinnacle Mountain to the southwest (1). Spread to the south reached a maximum rate of 48 chains (3,168 feet) per hour from 1430 to 1500 EST, decreasing thereafter.

During the fire's run, flame heights ranged from 10 to 40 feet with maximum flashes to 60 feet. Smoke columns slanted to the northeast with height and then leveled off, reaching maximum heights estimated to be 10,000 feet. Adjacent smoke columns were observed to converge with height. Fire whirlwinds with diameters of 15 feet and heights of 150 feet occurred in the fire area.

The fire continued to spread, but at a lesser rate, during the remainder of the afternoon and night. It was controlled by 0630 EST the next morning, when light rain began to fall.

THE METEOROLOGICAL DATA

To study the meteorological conditions of an event requires observations of a density and frequency commensurate with its scale. A forest fire is a comparatively small and rapidly changing event for which small-scale observations are seldom available. Conditions must be inferred by considering the larger scale meteorological environment in which the fire occurs. This procedure was used for the Hellgate Fire.

The data available for the Hellgate Fire consist of sounding observations for 0700 and 1900 EST; winds aloft observations for 1300 EST; surface observations from hourly reporting stations for 1300, 1400, 1500, and 1600 EST; and a surface observation for 1300 EST from the fire weather station at West Buena Vista, located about 3 miles northwest of the fire's point of origin. None of the observations were made at the site of the fire, although the one at West Buena Vista was reasonably close. The nearest hourly reporting stations were Lynchburg, Virginia, about 25 miles south-southeast; and Roanoke, Virginia, about 40 miles southwest. The nearest winds aloft station was at Beckley, West Virginia, about 80 miles west; and the nearest sounding station was at Greensboro, North Carolina, about 115 miles south.

SURFACE CONDITIONS

The Hellgate Fire occurred in the warm sector of an extra-tropical cyclone system (figures 3-6). Typically, a warm sector is characterized by warm moist air, but in this case the air was warm and exceedingly dry. Temperatures were near 80° F., and dewpoints were in the 30's. Surface winds were generally southwest to west at 15 to 20 knots with gusts up to 30 knots. The warm sector winds were a major factor in the rapid spread and spotting of the fire to the east and northeast.

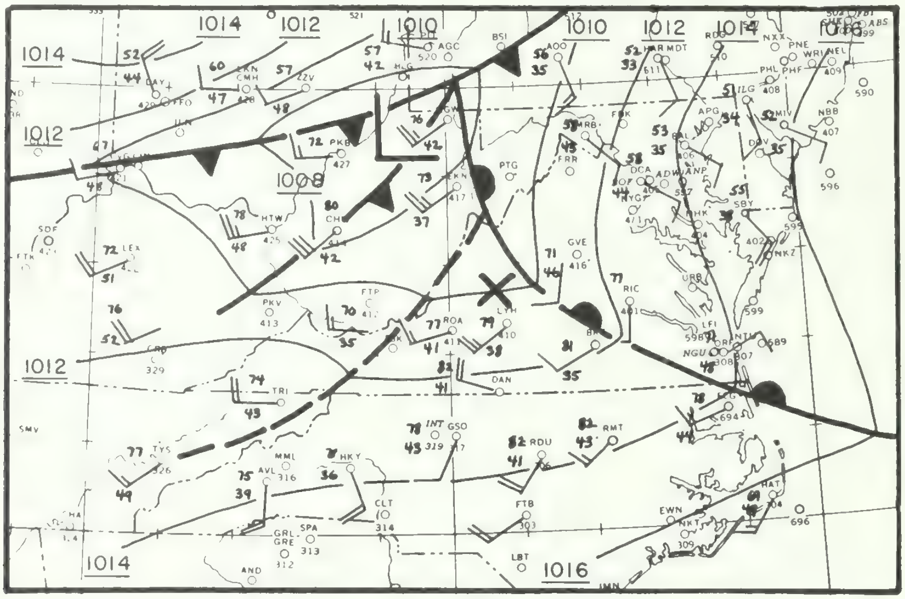

Figure 3. --Sectional surface synoptic analysis for 1300 EST. Wind, temperature, and dewpoint values are plotted. One whole barb of wind is equal to 10 knots; a half barb is equal to 5 knots. Gust speeds of winds were used. Isobars are drawn for each 2 millibars, and the low pressure center is indicated by an "L." Fronts are shown by conventional symbols, and the pressure trough line is shown by a heavy dashed line. The location of the fire is shown by an "X."

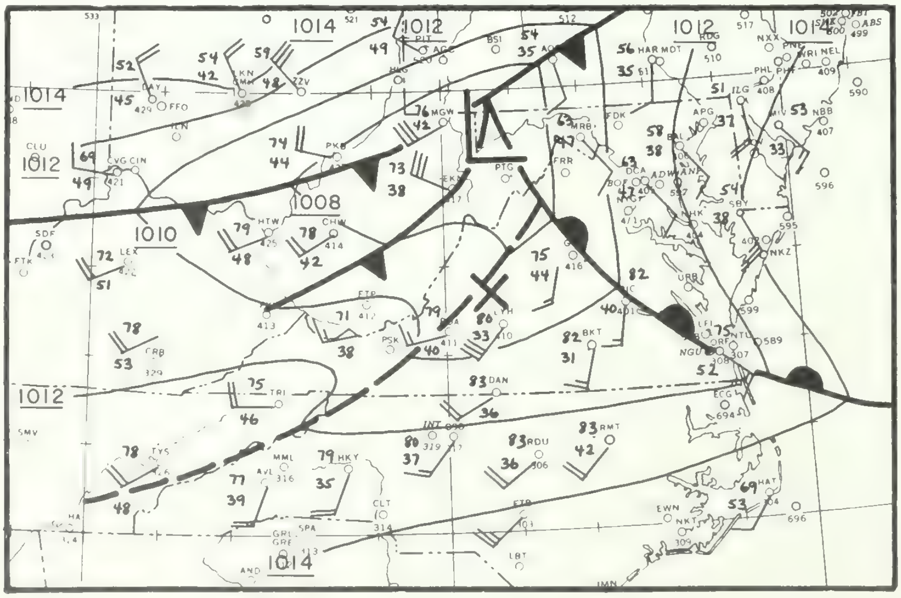

Figure 4. --Sectional surface synoptic analysis for 1400 EST. Note the proximity of the pressure trough line to the fire site.

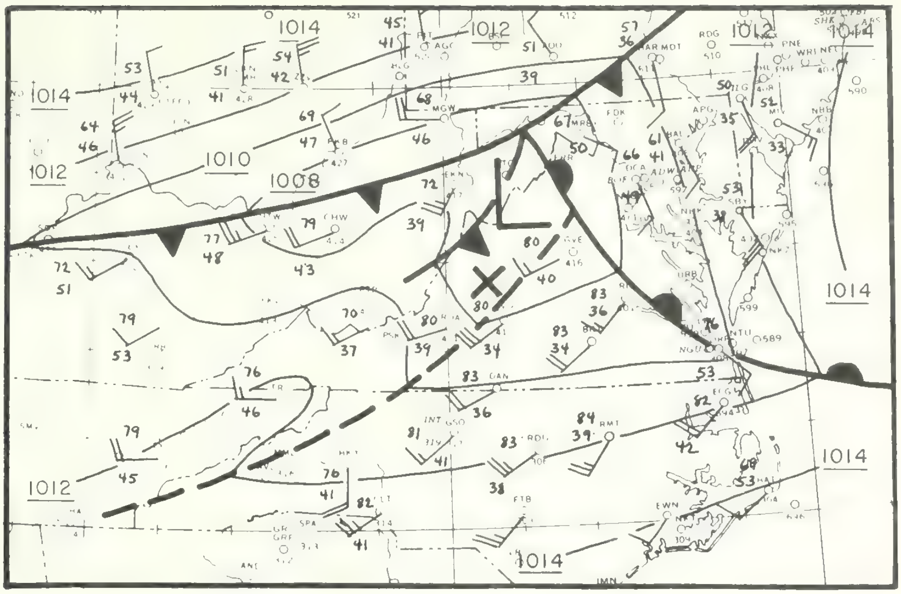

Figure 5. --Sectional surface synoptic analysis for 1500 EST. The pressure trough line had passed the fire site by this time.

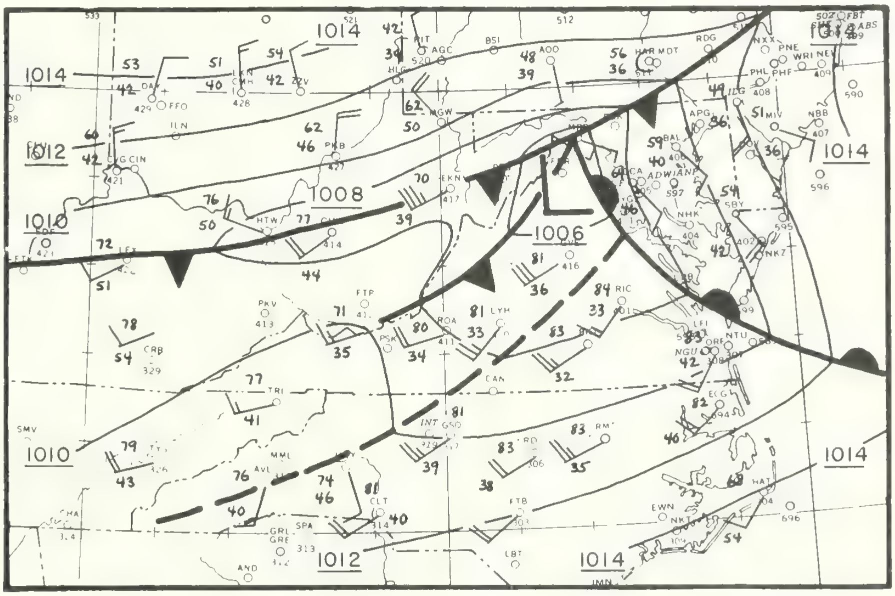

Figure 6. --Sectional surface synoptic analysis for 1600 EST.

The 1300 EST observation at West Buena Vista showed a dry bulb temperature of 79° F. and a wet bulb temperature of 57° F. The latter corresponds to a dewpoint of 38° F. and a relative humidity of 23 percent. Wind was south at 21 miles per hour (18 knots). The wind direction may have been influenced by local topography; the general flow, as shown in figure 3, was from the west-southwest. The warmth and dryness of the airmass, together with the wind speed, gave a spread index of 51 in the National Fire Danger Rating System, indicating EXTREME fire danger--the highest category. Except for wind direction, the 1300 EST observations at Lynchburg and Roanoke were similar to the one at West Buena Vista (table 1). Cloudiness at both stations consisted only of scattered, high, thin cirrus clouds above 20,000 feet, except for a few middle level alto-cumulus clouds at 12,000 feet at Lynchburg at 1600 EST.

Table 1. --Observations of temperature, dewpoint, relative humidity, and wind at Lynchburg (LYH) and Roanoke (ROA), Virginia, from 1300 to 1600 EST

Time EST	1300		1400		1500		1600	
Station	LYH	ROA	LYH	ROA	LYH	ROA	LYH	ROA
Temperature °F.	79	77	80	79	80	80	81	80
Dewpoint °F.	38	41	33	40	34	39	33	34
Relative humidity %	23	28	18	25	19	23	18	19
Wind direction	SW	WSW	SW	WSW	SW	WSW	SW	WSW
Wind speed knots	16	14	18	15	19	13	18	12
Gust speed knots	24	--	30	--	28	20	27	20

The warm sector of this cyclone contained a pressure trough line extending south-southwestward from the low center. The trough line was shallow at 1300 EST, but deepened as it moved east-southeastward through the site of the Hellgate Fire. Deepening was enhanced by the motion of the line down the lee slopes of the Appalachian Mountains (deepening is favored generally to the lee of mountain barriers) and by the time of day (pressures tend to fall during early and mid-afternoon). Microbarograms indicated that the pressure trough line passed Roanoke at 1420 EST and Lynchburg at 1535 EST. The interpolated time of passage at the fire site would have been approximately 1430 EST.

The warm sector of a cyclone system is favorable generally for convective activity; when a pressure trough line is also present, the most intense convection tends to be localized along this line. The rapid spread of the fire from 1350 to 1500 EST occurred during the passage of the pressure trough line, and it is inferred that convection was triggered and increased by its approach and passage.

Pressure trough lines are usually accompanied by shifts in the wind, which are part of the mechanism for increased convection. The wind shift may be characterized by a change in direction, a change in speed, or both. The amounts of change may be slight and of brief duration. Small but significant wind shifts did occur when the pressure trough line passed Charlottesville in north-central Virginia and Danville in extreme south-central Virginia, but the hourly surface observations at Lynchburg and Roanoke showed little change in the winds. Local terrain features may have suppressed wind shifts there, or the shifts may have occurred between official observation times. For example, a gust of 46 miles per hour (40 knots) was quoted for Lynchburg at 1330 EST (1), but no record of this was made on forms WBAN 10A and 10B, the official observational records of the station.

That the pressure trough line may have influenced the wind field is suggested by the manner in which the fire spread. Rapid spread of the fire to the east from 1400 to 1430 EST is indicative of a west wind ahead of the trough line. Subsequent spread of the fire to the south from 1430 to 1500 EST suggests a wind with a northerly component to the rear of the line. The latter instance is supported by reports of a wind shift by the fire crews (1).

The existence of a wind shift is further evidenced by the winds aloft pattern, which is discussed in a following section.

Local topography of the fire site and the fire itself undoubtedly modified the wind field, too. The rapid eastward spread of the fire from 1400 to 1430 EST suggests that winds were very strong. Using observed values of temperature and humidity for Lynchburg at 1400 EST (80° F. and 18%) and the spread rate of 110 chains per hour, extrapolated values of the Spread Phase Tables of the National Fire Danger Rating System yield wind speeds of 55 to 60 miles per hour. This estimate is crude and appears high, but it does indicate a substantial increase in speed which may have resulted from local topography and the effects of the fire. Using the spread rate of 48 chains per hour that occurred with the southward spread of the fire from 1430 to 1500 EST yields wind speed values of 15 to 20 miles per hour, which are consistent with values observed at Roanoke and Lynchburg. Unfortunately, direct wind observations at the fire site are lacking to verify these estimates.

FURTHER ANALYSIS OF THE SURFACE WIND FIELD

The surface wind field was analyzed to determine values of two kinematic properties: horizontal velocity divergence and the vertical component of relative vorticity. These are helpful in understanding the behavior of weather systems.

Horizontal velocity divergence, commonly called "divergence," is a measure of the net rate at which air enters or leaves a layer horizontally. When it is positive, air is depleted from the layer; when it is negative, air accumulates in the layer. In either case, air must then enter or leave the layer vertically to compensate for the amount depleted or accumulated. Positive divergence at the surface requires downward motion in the layer above the surface; negative divergence requires upward motion. Divergence computations provide a means of inferring vertical motion fields from horizontal wind data.

The vertical component of relative vorticity, commonly called "vorticity," is a measure of the rate at which air parcels rotate about a vertical axis. Positive values indicate cyclonic (counter-clockwise) rotation, and negative values indicate anticyclonic (clockwise) rotation. Small-scale circulations, such as tornadoes, funnel clouds, and dust devils, generally require conditions of positive vorticity.

Intensification of weather systems is favored generally in areas where divergence is negative and vorticity is positive.

Divergence and vorticity were computed and analyzed for 1300, 1400, 1500, and 1600 EST (for methods by which this was done, see (2) and (3)). Examples of the analyses are shown for 1400 EST in figures 7 and 8. One may note that centers of negative divergence (-50×10^{-2} hr^{-1}) and positive vorticity (28×10^{-2} hr^{-1}) were located in northern Virginia. with negative divergence and positive vorticity extending southwestward from the centers. Values at the Hellgate Fire site were -20×10^{-2} hr^{-1} for

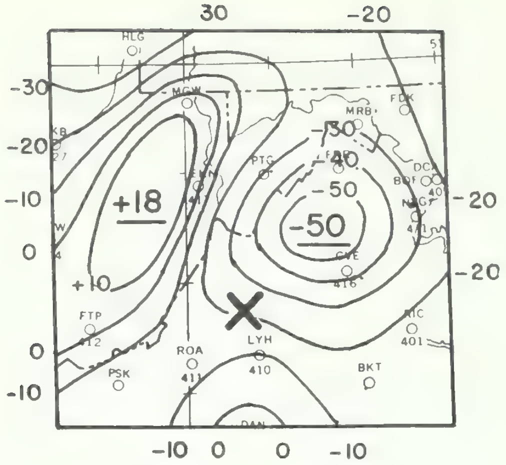

Figure 7.--Analysis of surface values of horizontal velocity divergence for 1400 EST. Isopleths are drawn for each 10 x 10^{-2} hr^{-1}. Note the negative center in northern Virginia and the extension of negative values southwestward through the fire site.

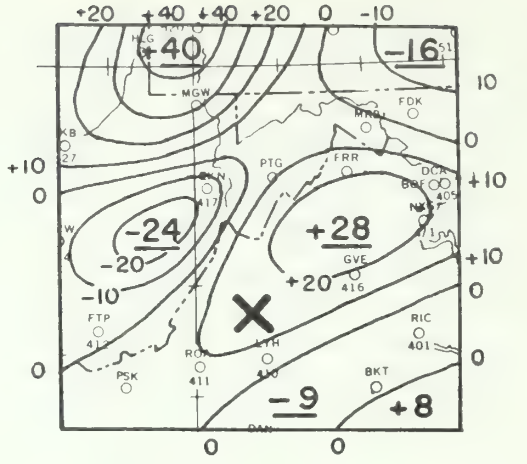

Figure 8.--Analysis of surface values of the vertical component or relative vorticity for 1400 EST. Isopleths are drawn for each 10 x 10^{-2} hr^{-1}. Note the positive center in northern Virginia and its extension southwestward through the fire site.

divergence and 12 x 10^{-2} hr^{-1} for vorticity. The centers were associated with the surface low-pressure center and its warm front; the southwestward extensions were associated with the pressure trough line.

The values of divergence and vorticity are numerically quite small because of the comparatively large scale of the computations. The data used consisted of wind direction and wind speed from hourly reporting stations, which are spaced from 50 to 100 miles apart; and computations were made with respect to a measuring interval of 100 nautical miles. Values of divergence and vorticity are critically dependent upon the scale of the data (3, 4), being small when large-scale data are used and increasing generally as smaller scale data are used. The values computed typify the large-scale flow in which the Hellgate Fire occurred. Values on the comparatively small scale of the fire site would have been substantially larger and would have been appreciably modified by the local topography and the fire itself.

Divergence at the fire site from 1300 to 1600 EST was positive, except at 1400 EST, when the negative value of -20 x 10^{-2} hr^{-1} was present (fig. 9). Positive divergence at 1300 EST, corresponding to large-scale downward motion, may have been the reason that smoke was "lying low" above the creek in Bennett's Run at 1340 EST (1). Downward motion would have repressed the smoke. Negative divergence at 1400 EST, corresponding to large-scale upward motion in association with the pressure trough line, appears to have contributed to the rapid spread of the fire, which began at 1350 EST and continued until 1500 EST. Convection would have already been present at 1400 EST, providing a natural draft for the fire. Positive divergence at 1500 and 1600 EST, corresponding to large-scale downward motion, appears to have been related to the reduced rate of spread from 1500 EST on.

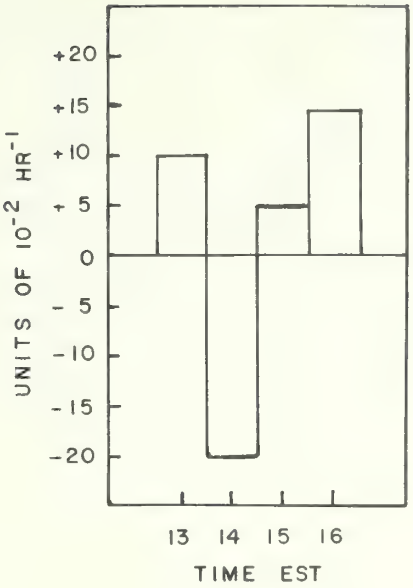

Figure 9.--Values of horizontal velocity divergence at the Hellgate Fire site for the period 1300 to 1600 EST.

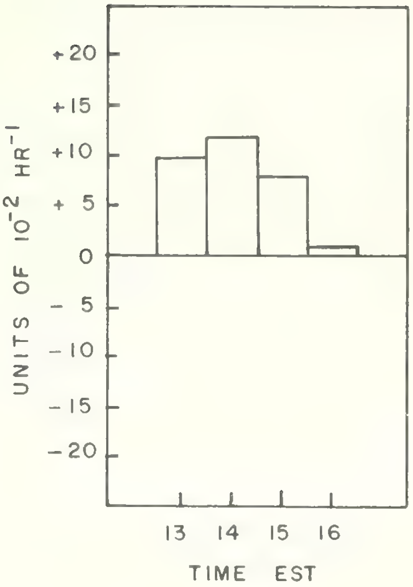

Figure 10.--Values of the vertical component of relative vorticity at the Hellgate Fire site for the period 1300 to 1600 EST.

Vorticity at the fire site from 1300 to 1600 EST was positive throughout the period, with a maximum value of 12 x 10^{-2} hr^{-1} present at 1400 EST and substantial values present from 1300 to 1500 EST (fig. 10). An appreciable tendency for cyclonic rotation would have been present from 1300 to 1500 EST, favoring the generation of fire whirlwinds. Direction in which the whirlwinds rotated was not reported (1), but cyclonic rotation would have been required to conform to the vorticity field.

The existence of large-scale negative divergence and positive vorticity at 1400 EST favored intensification of the fire.

THERMAL CONDITIONS ALOFT

A sounding from the surface to 700 millibars (about 10,000 feet) was computed for 1300 EST at the Hellgate Fire site by time and space interpolations from 0700 and 1900 EST observations at seven surrounding stations, except for surface values which were those of the 1300 EST observation at West Buena Vista. The sounding (fig. 11) is subject to some error because of the time and space interpolations required to construct it. However, this is considered a better approximation to conditions with respect to the fire site than any of the actual soundings, which were over 100 miles away and were made only at 0700 and 1900 EST.

The derived sounding indicates that the airmass was absolutely unstable from the surface to 5,000 feet, since the decrease in temperature with height was greater than the dry adiabatic rate. Once convection had been initiated at the surface, air parcels would have risen dry adiabatically, accelerating upward until they had reached an equilibrium temperature with their environment at around 8,000 feet. Parcels would

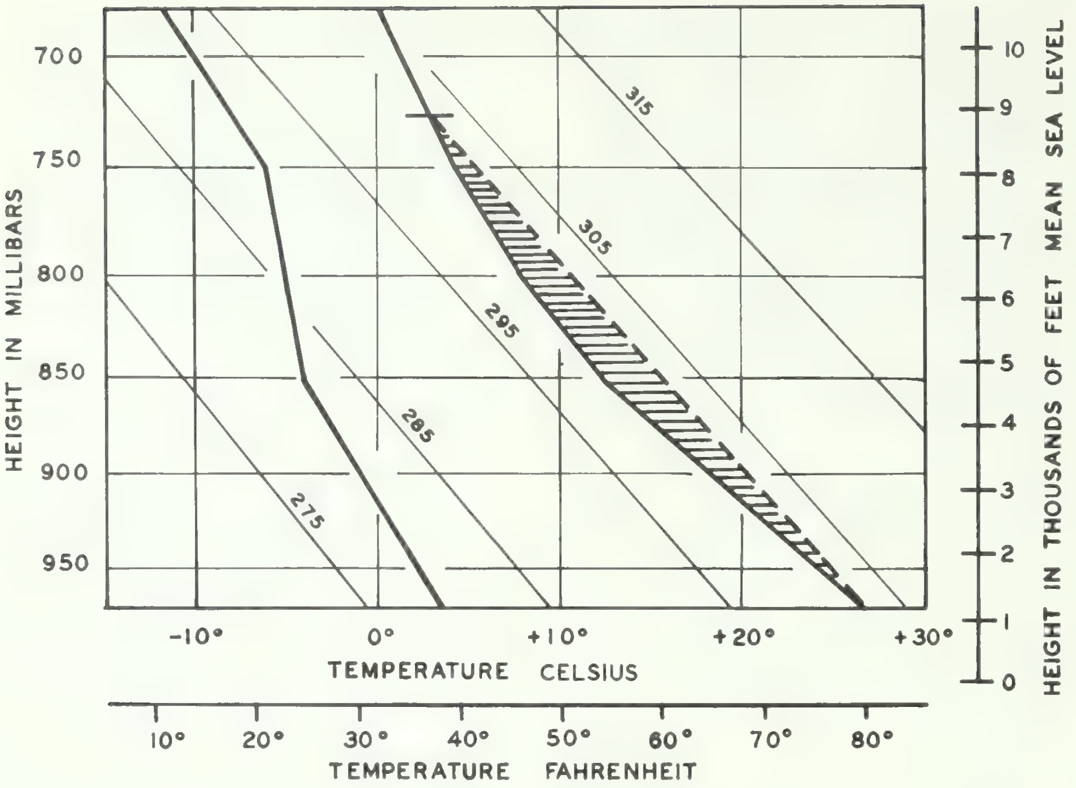

Figure 11.--Profile of temperature and dewpoint (heavy solid lines) from the surface to 10,000 feet mean sea level at the Hellgate Fire site for 1300 EST. Vertical scales are height in millibars and thousands of feet mean sea level. Horizontal scales are temperature in degrees Celsius and degrees Fahrenheit. Sloping lines are lines of constant potential temperature (dry adiabats) and are labeled in degrees absolute. The shaded area between the dashed and solid lines represents the energy available for free convection.

have continued to rise by their momentum at a decelerating rate to about 11,000 feet. However, because of the extreme dryness of the airmass, this convection could not have resulted in showers or thunderstorms.

It is believed that convection was triggered by the approach of the pressure trough line and its associated field of negative divergence shortly before 1400 EST, and that the resulting convection contributed to the vertical development of the fire. The observed extension of smoke columns to 10,000 feet (1) is in good agreement with the computed height of potential convection to 11,000 feet. The observed leveling off of the columns would have been a natural consequence then of the decelerating upward motion near the top of the convection. The dryness of the convection was evidenced by the absence of low clouds and the limited amounts of higher clouds at Lynchburg and Roanoke.

WINDS ALOFT

Marked differences in the 1300 EST winds aloft observations at stations surrounding the fire site precluded the selection of any one as being typical. These differences reflected the presence of the pressure trough line previously described. Winds to the west and north of the line were a little more westerly in direction and considerably greater in speed than those to the east and south. For example, Beckley, West Virginia, about 80 miles west of the fire site, had winds from the surface to 10,000 feet that ranged from 230 to 250 degrees in direction and from 20 to 38 knots in speed, whereas Greensboro, North Carolina, about 115 miles south of the fire site, had winds that ranged from 210 to 230 degrees in direction and from only 6 to 18 knots in speed for the same layer.

Interpolated profiles of wind direction and wind speed were prepared from observations at nine stations surrounding the fire site, but are not presented. Uncertainty concerning the exact position of the pressure trough line aloft, and its associated wind field, left some doubt about the validity of the interpolated profiles. In addition, the interpolations were unable to accommodate the effects of the local topography on the lower level winds.

Winds at higher levels were examined to determine a possible relationship between the jetstream and the fire. A direct relationship appears doubtful. The axis of the jetstream was about 300 miles north of the fire site, extending from southern Iowa across southern Michigan to southern New England, with a jet core maximum of 145 knots at 32,000 feet over southeastern Michigan. Winds at comparable levels over the fire site were only 85 knots.

CONCLUSIONS

Meteorological conditions at the time and place of the Hellgate Fire were critical with respect to fire danger and fire behavior. Specific conclusions are:

1. The fire occurred in the warm sector of an extra-tropical cyclone system which contained a pressure trough line.

2. High temperatures, low humidities, and strong winds produced a condition of EXTREME fire danger.

3. The airmass was absolutely unstable from the surface to 5,000 feet and was favorable for convection to 11,000 feet. Convection appears to have been triggered by the approach of the pressure trough line.

4. Rapid spread of the fire occurred from 1350 to 1500 EST and appears to have been related to the passage of the pressure trough line at 1430 EST.

5. Maximum rate of spread to the east at 110 chains per hour from 1400 to 1430 EST occurred with the approach of the pressure trough line.

6. Maximum rate of spread to the south at 48 chains per hour from 1430 to 1500 EST occurred following the passage of the pressure trough line.

7. Large-scale negative divergence and positive vorticity of the surface wind field existed at 1400 EST. These properties favored intensification of the fire.

8. The surface and low-level winds were undoubtedly influenced by the local topography and the fire itself. Rapid spread of the fire from 1400 to 1430 EST indicates that there was a local increase in wind speeds.

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Forests, Wildlife, and Habitat Management-- A critical examination of practice and need

by

Joseph S. Larson

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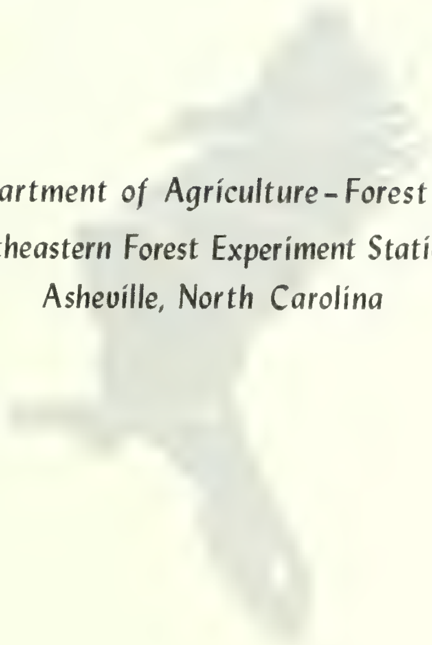

U.S. Department of Agriculture-Forest Service
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Forests, Wildlife, and Habitat Management--
A critical examination of practice and need

by

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INTRODUCTION

The history of the relationship between man and wildlife in the United States includes several stages, starting with the American Indian tribes, running through the conquest of the land by white man, and ending with man's attempt to protect, husband, and finally manage wildlife populations.

When it was realized around the beginning of the 20th century that many species of wildlife would be exterminated if action were not taken, a variety of efforts were made to "do something for wildlife." Legal protection, creation of refuges, and stocking of native and exotic species were typical action programs which characterized this period. Subsequent critical examination of a number of these efforts has shown that, although they were effective at the time, they were mainly stopgap measures which were not of long-term value to wildlife. As a result, and often accompanied by public protest, wildlife agencies have shifted from programs directly involving the animals to programs centered on habitat management. Thus, habitat management has largely replaced husbandry in the modern wildlife management program. Refuges, hatcheries, game farms, and buck laws have been shown to be of less lasting value than manipulation and restoration of the environment which wild species call home.

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Acknowledgments.--Many key personnel from state wildlife agencies and National Forests provided data for this study, and the author gratefully acknowledges the key role they generously played. Dr. Thomas H. Ripley, U. S. Forest Service, Southeastern Forest Experiment Station, initially recognized the need for a study of this type, arranged material support, and gave professional encouragement throughout. Professor Thomas C. Evans, formerly Department of Forestry and Wildlife, Virginia Polytechnic Institute, provided continuing guidance and critical review of a very valuable nature. The University of Maryland, Natural Resources Institute, provided support during preparation of the final report.

However, the pressure for action programs which leave some visible mark on the land has continued. Public demand, channeled through public-sensitive administrators, has resulted in land management programs vast in scope and high in cost. Among these is the very extensive and often intensive creation of agricultural clearings in forested areas for wildlife habitat improvement. The following report is a critical review of this practice.

Study Objectives

1. To determine the nature and extent of the forage clearing practice in forests of the Eastern United States for game animal management.

2. To evaluate critically the present body of knowledge concerning the contribution of this practice as a basis for:

   a. Programing effective research

   b. Providing guides for interim management policies and procedures pending expanded knowledge.

Definitions

By definition, this study is concerned only with one type of clearing practice; namely, clearings in forest habitat, natural or manmade, which are maintained in natural or artificially planted agricultural forage crop species. These forest clearings may be simply natural grassy openings, or clearings which have been planted and maintained in an agricultural crop for wildlife. Maintenance may be as simple as periodic mowing to retain a certain botanical composition, or may entail annual plowing, disking, liming, fertilization, and seeding.

It is recognized that sprout clearings, seeded utility rights-of-way, trails, skidroads, and fire lanes are associated types of forest-wildlife management. Each of these have values under a wildlife management program but will be only incidentally mentioned in this study.

The writer has found confusion in the literature concerning the use of the term forage. For the purpose of this discussion, forage species are defined as herbaceous agricultural or native plants. Where used, the term browse means woody vine, shrub, or tree species.

Organization of the U. S. Forest Service Regions mentioned herein is in accordance with the organization which was in effect on May 31, 1965.

SOME BACKGROUND MATERIAL

In the course of the original study the writer made an extensive review of the literature pertaining to clearings (119 North American and European references cited), conducted field inspection trips in 11 states, obtained data by personal interview with key personnel from 10 additional states, and received data from 3 states through correspondence alone. These data are presented in considerable detail elsewhere, and the reader is referred to it for more specific information (Larson 1966a). For present purposes, a summary of this material follows.

Organized programs of clearing installation started in 1935 and have involved 22 eastern and southeastern states. Over 30,000 acres of forest land have been cleared. The present status of the programs in each state is varied (table 1). One-third to one-half of the total acreage in forage clearings occurs on National Forest land, and clearings in general occupy sites which are less desirable for other land-management

Table 1.--Acreage in clearings, initial year of installation, and status of clearing program by states

State	Clearing size	Initial installation	Status of programs
	Acres	Year	
Virginia	4,255	1936	Cutting back since 1959
Pennsylvania	4,000	1935	Cutting back since 1950
Illinois	3,600	1950 - 1954	Continuing
Tennessee	3,244	1950	Leveling out since 1957
West Virginia	2,108	1945	Cutting back since 1950
Maryland	2,090	1936	Cutting back since 1945-50
Mississippi	2,000	1935 - 1939	Cutting back since 1959-60
Kentucky	1,220	1946	State stopped in 1950-55; U. S. Forest Service is continuing
Florida	1,181	1947	Cutting back since 1960
South Carolina	1,000	1948	Cutting back since 1950-55
New Jersey	1,000	1946	Continuing
Indiana	882	1953	Continuing
Alabama	875	1945 - 1946	Continuing
Georgia	640	1945 - 1949	Cutting back since 1962
Ohio	500	1935	Ceased in 1962
Louisiana	453	1954	Continuing
Missouri	425	1959	Ceased in 1963
North Carolina	350	1949	Leveling out since 1964
Texas	200	1940's	Stable
Massachusetts	108	1964	Experimental
Oklahoma	60	1950	Ceased in 1960-64
New Hampshire	15	1951	Ceased in 1953
Total acres	30,206		

programs. With some notable exceptions, most states continue to maintain clearings already established; but trends indicate that new clearings will be established at a reduced rate.

The U. S. Forest Service's Region 8 distinguishes between forest openings and agricultural forage clearings and does not encourage creating the latter. Regions 7 and 9 do not make a distinction; and in the Shawnee National Forest, the State of Illinois pays the Forest from $70,000 to $90,000 annually to install forage clearings.

Agricultural clearings are created in the same manner, with some exceptions, in all states. Trees are removed, a seedbed is prepared and sown, and lime and fertilizer are applied. A great variety of crops have been tried by managers, mostly on a trial-and-error basis, though recommendations of state agronomists and the U. S. Soil Conservation Service have been important influences. Few records of success or failure have been kept on crops (a detailed list of crops tried in the various states appears in Larson 1966a).

Mowing, ranging in frequency from twice a year to once every 2 years, is the most common crop-maintenance procedure (outside of soil amendments) for perennial species. Complete renewal of clearings ranges from once a year to once every 5 to 10 years. Some states renew their clearings each year as a matter of practice. One state reported that this was done to justify having the men and equipment on hand, despite the fact that a permanent forage planting could be maintained with less frequent treatment. Soil tests are used sparingly, often only at the creation of a clearing, with all future soil amendments based on it alone. One clearing in a group may be deemed representative of the whole, or "standard" applications of lime and fertilizer may be used, based on the practices of the nearest farmers growing the crop in question.

Clearing sizes range from 1/10 to 60 acres. The most common lower limit is between 1/4 to 1 acre, and the most common upper limit is between 10 and 20 acres. Average sizes of clearings run from between 1/2 to 3/4 acre to 5 and 7 acres, most commonly 1 to 3 acres. Size and shape of clearings are usually dictated by the available site; and selection of sites is usually dictated by location of public land, forest-management policies, and existing openings. Percent of area goals and patterns of clearing installation varied widely, but the writer failed to find any objective evidence or investigations to support these. In fact, the tendency has been to accept various percent goals which have a basis in common sense, aimed to meet an immediate administrative need, and then to settle for whatever percent or pattern the topography of an area permits.

When biologists were questioned about the major role clearings play in their forest-game management programs, provision of supplemental food was by far the most frequently cited role. Fourteen of the states gave this as the major contribution and four others ranked it in second place. Second cited among the major roles of clearings was the addition of "edge effect." Nine states reported this as the primary role and three placed it second. Three states felt that influencing harvest of game animals was the prime role of clearings, three placed this factor second, two placed it third, and one placed it fourth. Three states felt that public relations value was the first role of clearings, three put this item second, and one third. Three states put influence on animal distribution first, one ranked this second, and one third in order of importance. A number of states expressed opinions indicating that alternative methods could or were being employed to achieve the same objectives originally ascribed to clearings.

There is almost a complete lack of studies to measure wildlife utilization of vegetation planted on clearings or to measure the effects of clearings on animal numbers or distribution. There is a similar lack of information on the effect clearings have on hunter success, distribution, and use of management areas.

In conjunction with this study, the writer tested a statistical sampling approach for measuring forage production and utilization on ladino clover clearings and reported on this in another paper (Larson 1966b).

DISCUSSION

The Rationale for Clearings

Wildlife management, based on habitat manipulation, is closely tied to ecological changes, both natural and manmade. Deer, turkeys, and ruffed grouse are referred to as forest game species; and it was earlier believed that the preservation of large tracts of forest land automatically meant preservation of good habitat for these species. This was a leading reason, among others, for establishment of National, State, and local forests which would be free from unregulated timber operations. Much of the land so dedicated had been cut or burned several times before it was abandoned to poor agriculture and later dedicated to growing trees again. These lands were of a broken and diverse cover at the outset. Following protection and reintroduction, forest game species started to increase in number, thus lending support to the contention that forest protection was the major tool in forest game management.

As time passed and the forests developed into pole-stage stands with rapidly closing canopies, game populations and food supply became unbalanced. In general, it became evident that large, mature forest tracts were not the utopia for forest game as was once generally believed. It was soon realized that optimum forest game habitat existed at a point somewhere in the middle of the sere between bare land and climax forest. This realization, and related factors observed among farm game, led to the concept of wildlife habitat management.

Apparently forest game populations are, and probably were before the 1600's in North America, most numerous under conditions which provide at least in part some open canopy, some thick brush, some grassy open areas, in short, some diversity of vegetative types. In nature this condition is most frequently caused by accidental natural events. The term "disruptive ecology" is applied by some to this condition. Following elimination of forest game habitat (logging, related fires, etc.), man had to turn full cycle to the return of mature stands before the significance of partial disruption or diversity was realized. Having learned this lesson, game managers made an effort to create situations in which forest game could not only survive but provide a surplus for recreational harvest. Agricultural clearings were, and still are, in many areas a major tool used to create the diversity needed.

Just because a tool will do the job in some situations is not sufficient basis for its selection in all cases. The correct selection of the tools may involve all of Wilm's (1952) steps of logic, exploration, experience, and experiment. This study provides the basis for deciding to what extent wildlife management as a profession has utilized these steps in choosing the agricultural clearing as a major tool, and to what extent it has tended "to dive into the physical part of the work without adequate advance planning" (Longwood 1962).

The Need for Knowledge

Present knowledge of the food and cover requirements of forest game indicates that some diversity in vegetative cover is necessary to sustain huntable populations. The basic observations of Leopold (1930, 1933) and Stoddard (1936) regarding needs for openings in the forest are logical and their validity has been fully demonstrated. The description of the prime turkey range in Virginia by Mosby and Handley (1943) included observations of an apparent relationship between turkey abundance and forest openings at that time; but they avoided specific recommendations of how much and where, leaving this to the discretion of the area manager. However, it is the lack of a means for determining these answers, for various locations, which is the basic underlying problem today. These are not new questions. Gabrielson (1936) was quick to ask them; Hosley (1942) asked for research 10 years after the need for diversity was first advocated; Graham (1947), during the big push for habitat management following World War II, stated that creation of openings solely for deer could not be justified; and more recently Bailey et al. (1951), McGinnes (1962), Krefting (1962), and the Northeastern Forest Wildlife Research Committee (1964) have voiced general and specific needs for research to determine how much, what kind, and where.

The persistent call for a factual basis for the use of clearings and repeated expression of reservations from active workers in the field are in themselves strong indicators of an untenable situation. On the other hand, the use of clearings has been widespread and intensive in many areas. The magnitude of the practice amounts to an irresistible force which few agencies and fewer individuals publicly discuss. The public has been almost universally pleased with the appearance of clearings, administrators and managers use them as highlights on show-me trips, and there has been generated an inherent feeling of goodness and justification towards any activity which feeds wildlife. Despite this, careful inspection of the means of providing a disruptive ecology leads the writer to suggest that it is, in the main, impulsive disruption.

A Critical Appraisal

A broad look at the use of clearings among the eastern states fails to show any consistent pattern of practice which can be associated with an ecological fact base. In fact, the design of the pattern seems most closely associated with political exigencies. States sharing similar biotic communities differ radically in the use of agricultural clearings, leading to the suspicion that the governing factor is not biological. This suspicion is further encouraged by the fact that U. S. Forest Service, although consistent in its policy within one Region (which includes states holding differing views), has differing policies between Regions; and Regional boundaries are mainly political in nature. The only significant trend discernible from a broad inspection is that which includes time as a factor. In the main, those states which have had the longest experience with agricultural clearings are showing a tendency to quietly withdraw or deemphasize the program.

The very nature of agricultural clearings is dominated by commercial agricultural techniques. The physical characteristics of a new clearing are those of an improved pasture for domestic stock. In some cases this condition is carefully maintained each year, whereas in others a period of senescence is reluctantly permitted before intensive renewal is imposed. That such clearings are supposed to supply an essential "natural" requirement in the environment of forest cannot be accepted by "naturalists." This is not objective criticism, however. What is more to the point is the observation that expensive techniques, such as seeding, plowing, liming, fertilization, and mowing, should at least be demonstrably superior to or more practical than less expensive measures. Here again, practices which logically should be comparable differ widely. Some states simply create an opening and conduct only enough maintenance to insure that it remains fairly open and somewhat more attractive to wildlife than the adjacent forest. Many states maintain their clearings through an intensive program resembling farming. On the other hand, they neglect periodic soil tests and make no serious effort to match soil amendments to soil conditions. Selection of crops favors those which are high in vegetative production and low in maintenance requirements rather than those which will supplement a demonstratedly deficient diet.

Many biologists discussed at length with the writer the most desirable shape and size for a clearing. Few topics called forth as detailed discussion as did these. It was a distinct disappointment to discover in practice that these considerations were largely theoretical and that the shape and size of the available site were the final deciding factors. The same can be said, in general, about dispersion of clearings on a management unit. If the funds were on hand, every accessible and available site was usually developed. Using a very conservative estimate ($100/acre for cost of installation; 1/4 mile of access road per clearing at $100/mile), these agricultural clearings have a minimum replacement value of at least $3.7 million. Conservative estimates for annual maintenance ($25/acre for an average of 5 years per clearing) indicate that nearly $4 million has been invested in maintaining clearings.

Although provision of food and "edge effect" were the prime reasons offered as the major roles of agricultural clearings, no state had conducted reliable studies of actual food production on agricultural clearings; and no edge effect studies applicable to a program of clearings had been made. Evaluations of clearings by key personnel were varied in emphasis and several indicated that the programs were valued more for their expedient nature than for their contribution to the ecology of the game habitat.

Open Questions

Our deficiencies of knowledge can be illustrated, in part, by a sampling of questions raised and left unanswered during the course of the study:

1. What are the effects of brushpiling around the edge of clearings on animal use?
2. What form of seedbed preparation, if any, is optimum under a given set of circumstances?
3. Should topsoil be turned under or not on sites where soil is shallow and dry?
4. Are silvicides a suitable tool in opening up new sites for agricultural clearings?
5. How does one determine which is the best vegetative composition for a clearing?
6. What are the guidelines for use of soil amendments?
7. Should a maintenance program include annual renewal, renewal every few years, or simply mowing the brush and adding cheap fertilizer as needed?
8. What is the optimum size and shape of a clearing for a given game species?
9. What pattern of distribution or density of clearings is optimal?
10. Do game animals use the center of clearings regardless of size and shape?
11. How can one decide whether agricultural clearings are desirable or not?

These are not important questions in every case, in light of the total problem, but they illustrate the dilemma which wildlife managers still face, despite a long history of the use of agricultural clearings. Perhaps the last listed question demands priority over all others.

CONCLUSIONS AND RECOMMENDATIONS

The general goal of this study, in addition to a critical review of the state of knowledge regarding agricultural clearings, was to create some order out of the confusion which has characterized this practice. To achieve this goal, it is necessary to offer some evaluations based on the critical review. The formation of these evaluations avoids the temptation to judge specific clearing practices found under field conditions in favor of a more meaningful evaluation of the bases of the practice.

At the outset of the study it was evident that professional wildlife managers had developed an array of conclusions about clearings. These conclusions have directly influenced the course of the use of agricultural clearings. To say the least, the practice has been characterized by heterogeneity; and it is evident that this has occurred because of a basic divergence of conclusions among the wildlife managers themselves. The degree of divergence can be partly attributed to a lack of communication among workers responsible for making land management decisions. Professional conferences have traditionally based technical sessions on animal topics, and the managers whose duties are concerned mainly with manipulation of vegetation for several species have not always found a readily available podium to present their problems for review.

This study evaluates the host of conclusions arrived at by managers and, in the light of existing knowledge, appraises these conclusions as: (1) Valid; (2) Invalid; and (3) Tentative or meaningless, pending more information. The last category (conclusions drawn in areas of insufficient information) gives rise to research needs. Identification of these research needs and assignment of priorities for research constitute the recommendations offered by this study.

EVALUATION OF CONCLUSIONS DRAWN BY GAME MANAGERS

Although not all managers may subscribe to any one of them, nor any single manager accept all of them, the critical review suggests that these general conclusions prevail among wildlife managers:

1. Forest game abundance is largely correlated with diversity of vegetative cover
2. Vegetative diversity should include openings in the canopy
3. Openings should be created where lacking
4. Agricultural treatment of openings will supplement the food base for forest game
5. Supplemental agricultural food plantings are essential for forest game species.

The following more specific conclusions also prevail:

1. If openings are to be created, it is only logical to complete the effort by planting a desirable agricultural crop
2. Standard agronomic practices or local farming experience provide the best guidelines for treatment of agricultural clearings
3. Size and shape of clearings are important considerations influencing animal use, food production, and general management
4. Location of clearings on proper soil sites is an important factor in new field installations
5. Percent of a management unit devoted to clearings and pattern of distribution of clearings are important factors affecting animal use and general management
6. Agricultural clearings as such provide supplemental food and necessary "edge" for forest wildlife species
7. Public relations are aided by the use of agricultural clearings
8. The observations that game species are seen on agricultural clearings and eat the planted crops are sound evidence in support of this practice.
9. Human use and distribution over a managed area are influenced by clearings
10. Economic studies of game management are not practical or necessary.

Evaluation of General Conclusions

Because the game species considered in this study evolved under conditions of vegetative diversity, the first general conclusion, that diversity is needed for optimum game production, is valid. Fire, disease, and other natural agents of forest destruction, along with man, have long created openings in the forest. It is reasonable to conclude, therefore, that diversity has a necessary role in managing forest wildlife habitat; and it suggests that where diversity does not exist it should be deliberately created by game managers.

The conclusion that agricultural clearings supplement the food base of forest game is valid only with respect to the addition of plant species which otherwise would not be found on the natural range. It is true that to some degree they change the food base, but in general usage among managers the term supplement implies beneficial change or addition. Insofar as this conclusion makes this implication, it falls in the area where meaningful conclusions cannot be drawn. To evaluate reasonably the supplemental role of agricultural clearings in terms of the food base, it is necessary that a food resource base line be established for any given management area. Although it is fairly easy to make an estimate of the quantity and to some extent the quality (in terms of value to game species) of food to be produced by a given acreage of agricultural clearings, this is of no value unless accompanied by base line information on what is already available. The writer has been unable to discover any instance where such information has been prepared in conjunction with use of agricultural clearings.

In addition, it must be made clear that base line information on the existing food resources has no value unless reliable estimates of the kinds and numbers of animals to be served are also available. Davis (1963) reports that present-day methods for estimating animal numbers can detect only large changes of populations and that detection of much less than 25 to 50 percent of a population is unlikely. From a practical viewpoint, Taber (1961) says of black-tailed deer: "Another impediment to efficient herd control is the fact that populations of deer cannot be counted accurately and easily. The trial-and-error method of balancing herds to their habitats looks to some citizens like incompetent thinking. Game biologists are often distrusted." Unless these deficiencies are corrected, many of the generally accepted conclusions regarding the use of agricultural clearings in forest game management will continue to be valueless as management guidelines.

The foregoing provides sufficient evidence that it is invalid to conclude that supplemental food plantings are essential for forest game species.

Evaluation of the Specific Conclusions

To a large degree, the specific conclusions just outlined have evolved concurrent with the use of clearings and following the acceptance of most or all of the general conclusions. Insofar as some of these stem from general conclusions found invalid or without substance, it may seem to belabor the point to evaluate them further. However, the writer has been party to earnest discussions among managers on all of these points and believes that a retrospective evaluation of each will add pertinent thoughts or perspective to the total problem.

Planting crops.--Apparently, many agencies and managers have decided that once the effort to create an opening in the forest has been made, it is logical to plant the area to a desirable crop which will supplement the food supply and maintain the open character of the clearing in opposition to natural succession. Sometimes this has been done with the explanation that once all the funds for gaining access and creating the opening have been invested it costs little more to plant it. The problem here is that, though the initial planting is inexpensive in comparison to the outlay which preceded it, the maintenance required over the years ahead may exceed all other costs if the plan is to retain the botanical composition of the planting. The value of planting the opening depends on the expected cost of maintenance and on the purpose of the planting. Presently, planting to supplement the food supply cannot be justified one way or the other, but planting or treating an opening to insure its open character with as little cost as possible is in keeping with the valid objective of supplying openings in the forest.

Treatment guidelines.--Many wildlife managers have received their training within the agricultural complex of a public university and are rightfully impressed with advances in agronomy with regard to improved forage crop production. As a result they have often turned to agronomists for information on treatment of clearings or have transferred a practice from a successful local farmer to their forage clearings. Even assuming that supplemental food planting is a valid practice, the standard agronomic approach to species selection and soil amendments is not valid unless the manager can give the agronomist an accurate estimate of the grazing pressure the area will receive. In addition the agronomist needs accurate information on what other food supplies are available to the animals which will use the clearing. These factors are necessary in deciding which species and related soil treatments to recommend. Wildlife managers have frequently been surprised to find agronomic recommendations are expensive, and the writer suggests that this is often true because agronomists work with cash crops and little experience has been accumulated on such transient feeders as deer and turkeys. Until the manager can provide the necessary estimate of animal users (grazing pressure) and an inventory of other foodstuffs, there is no basis for evaluating agronomic recommendations for agricultural clearings.

Size and shape of clearings.--The question of optimum size and shape of clearings is one which requires more information than is presently available. Lewis' (1964) study in Tennessee, which showed that turkey use was higher in clearings 10 to 20 acres in size, is the only experimental evidence that clearing size may influence animal use. His findings are yet to be tested elsewhere and on other species, such as deer. Close examination of the experience of the various states fails to indicate any trend in size or shape of clearings which can be associated with any clear benefit to game or harvest. Such factors as available funds and personal preferences of managers frequently influence size and shape as much as anything else. Many managers find that rectangular clearings are easier to cultivate by machine and that several 1- to 3-acre clearings can be more efficiently treated than can the same acreage broken up into $\frac{1}{4}$-acre openings. Outside of this latter consideration, the value of which is dependent on future evidence that cultivated crops are desirable, meaningful conclusions cannot be presently made about shape and size of clearings. There is evidence, through Lewis' (1964) study, that the means exist for obtaining the information.

Soil-site factors.--Regardless of the ultimate decisions about what vegetation should be encouraged on clearings, soil condition will always be a valid consideration. There is little evidence, except in early attempts to establish clearings on purely geometric grids or exact linear distances, that managers deny the importance of soils on the clearing site. On the other hand, in the two states where detailed soil information was available on large forested tracts (Cumberland and Monongahela National Forests), only one was making use of it with regard to clearing installation. Few managers made regular use of soil tests. The conclusion that soil condition deserves consideration is unquestioned, but detailed maps are lacking and managers regularly fail to make use of even the little information and routine tests which are available.

Percent of area and patterns.--Conclusions on percent of a management unit to be devoted to clearings and pattern of clearings have been drawn since the use of clearings began (Jackson et al. 1935), but the question remains uppermost in the minds of most managers and administrators today. Despite the persistence of the question, the evidence is that there is still no reasonable basis upon which to draw meaningful conclusions. The concept of different patterns and densities of clearings within a forested area implies measurable effects on game or game harvest. As has been discussed previously, the means to detect adequately the changes in animal numbers have not been developed. Adequate information on animal behavior for the forest game species considered here is not available. Experience among the states fails to indicate any trends attributable to improved management or harvest. Until adequate means of estimating animal numbers are developed, and until more attention is paid to game ethology, reasonable bases for drawing conclusions on density and distribution of clearings will continue to be lacking.

Role of clearings.--The fact that over 30 years of experience with installation of agricultural clearings has produced such a variety of concepts concerning application is additional evidence that there is probably not a commonly agreed upon role for clearings. It may even indicate that there is not universal agreement on the goal of game management itself. In addition, the assumption that animal production is an index to the success of game management underlies much of the discussion in this study, but it too is subject to critical examination.

Edge effect.--"Edge" is, in a sense, the boundary of the elements which determine diversity; and it may be the most important component of diversity as far as forest game is concerned. As such, edge is combined with the valid need for diversity and is an important consideration in creation of clearings. Unanswered still, however, are the questions of how much, where, and what kind of edge is necessary. Answers to these details depend on determination of animal needs, and this in turn depends on better information on animal behavior and range food inventory. In short, "edge," a basic component of diversity, is needed, but the quantitative and qualitative aspects of this need remain open to question.

Public response.--There is abundant evidence that the public is enthusiastic about agricultural clearings. Such approval is not surprising, for the conservation-minded layman is easily impressed by a conservation effort as obvious as artificial feeding, and particularly so if the effort may be readily observed. Indeed, because most managers are under constant public pressure, public approval is an important, although not an objective, criterion for evaluating a practice. It may often be necessary, in fact, to conduct certain practices which appeal to the public if only to perpetuate other, more valuable aspects of the game management program. But the scientist and the manager cannot, or at least should not, permit the subjectivity of mere approval to dominate objective decisions and their proper criteria for making decisions. Both must maintain a clear professional differentiation between public relations efforts and the biological aspects of habitat management.

Observational evidence.--The evidence of concentrated tracks, droppings, animal observations, and animal removal of planted crops on clearings can be highly persuasive evidence that there is a need for agricultural clearings. It is extremely satisfying to a manager to find his efforts so well received by the game and the public. Unfortunately, this reaction is misleading because the expression of need and preference is not synonymous. Opponents of agricultural clearings ask whether they represent "ice cream or meat" in the dietary needs of game, and proponents challenge them to show that game make as much use of alternative practices. This argument has more life to it because definitive, or even practical, answers are not forthcoming until we are able to assess the effects of clearings, and their alternatives, on game and harvest. It must be remembered that game managers are not in the business to produce tracks, droppings, or bales of vegetation. This is another important area where meaningful conclusions cannot be made until improved methods of animal estimation are developed and more is known of forest game behavior.

Influence on human use.--Human use and distribution over a tract of land has always been influenced by access and access ways. Insofar as a system of clearings provides access, it has a profound influence on human use of an area. The attractiveness of clearings will have some effects on some hunters and other users of management areas. Special demands, such as those made by bow hunters, may be directly and positively served by openings. To this extent, agricultural clearings play a valid role in the hunter-management program. Access is possible, however, without clearings simply through construction of roads and trails. And, clearings need not be planted to agricultural crops to permit unimpeded flight of an arrow. The ultimate question to be answered is, to what extent do agricultural clearings and their alternatives increase man-animal contacts? Close inspection of the experience of the states uncovers no objective information on which to base an answer, and more information on not only animal but also hunter behavior is still required.

Economic study needs.--Few economists are found among wildlife managers, and input and output evaluation of game management practices has not been customary. However, this is not sufficient justification to deny the values of this area of inquiry and its applicability to wildlife management. Management practices are becoming more expensive, and the area of land available for management is on the decline. Costs per unit of area are sharply rising, and the writer suggests that if pressures to inspect the economics of management do not soon originate from within the management group they are sure to arise from the outside. Already competitors for land areas are effectively using economics as a persuasive tool to compete with wildlife resource interests. Although wildlife represents a resource which does not lend itself easily to classical economics studies, the possibilities have not been exhausted. It is not valid to conclude that such studies are impractical or unnecessary.

It should be recognized, however, that at the current state of knowledge it is not pertinent to propose such studies at the level of direct management. The pertinent level for economic inquiry is presently more basic than simple cost accounting related to isolated habitat manipulation techniques. Even assuming that animal production is an index to the success of wildlife management, the definition of the actual commodity produced is still largely unresolved. Are animals bagged by hunters always the end product, or are animals seen by unsuccessful hunters also legitimate products? Is an animal photographed by a naturalist a product as well as one taken as a trophy? Does economic success of management always rest on increased numbers of animals, or can increased man-animal contacts with no increase in animals constitute a desirable product of management?

Following definition of the product of game management is the task of identifying the pertinent inputs of the production process and determining how they act as independent and related variables. These inputs comprise not only biological factors but include such socio-economic factors which express themselves through changes in broad land use and demand for public recreation. And finally, there is the unresolved question of the economic value of the game management product.

Improved information in these three areas is a prerequisite to attacking the economics of management decisions which are related to: Reduction of cost per unit produced; choice of management practices to achieve the desired level of output; desired intensity of management to achieve the greatest private or general social return from game management.

Photo courtesy of Virginia Commission of Game and Inland Fisheries

A series of clearings on a forest in Virginia.

Photo courtesy of Virginia Commission of Game and Inland Fisheries

A completed clearing in Virginia.

CONCLUSIONS IN SUMMARY

In summary, it has been possible through a broad critical review to evaluate the array of conclusions which have directly influenced the use of agricultural clearings in forest game management. The evidence indicates that the following are valid conclusions:

1. Diversity of vegetative cover is correlated with forest game abundance
2. Openings are a necessary component of forest-wildlife habitat
3. Where openings do not exist, they should be created
4. Based on the current state of knowledge, agricultural clearings supplement the food base of forest game only through introduction of additional plant species
5. Planting or encouraging growth which will tend to maintain the open character of a clearing is a valid effort as long as least expense guides the selection of the technique
6. Soil condition on prospective clearing sites is an important consideration frequently given only lip service in practice
7. Edge as a basic component of diversity is a needed factor contributed by clearings
8. Agricultural clearings have value as a public relations tool, but with decided reservations
9. Human use of an area is directly influenced by the access pattern afforded by an existing system of clearings but, except for special requirements such as bow hunting, the clearings themselves contribute little to the actual use.

The following conclusions appear at this time to be invalid:

1. Supplemental food plantings are essential for forest game species
2. Economic studies of game management are not necessary.

The following are features of agricultural clearings for which meaningful conclusions cannot be drawn because information is lacking:

1. The qualitative and quantitative means by which agricultural clearings may supplement the food base
2. The role agricultural clearings play in game production
3. The value of planting clearings to crops which involve expensive maintenance
4. The applicability of standard agronomic recommendations as guidelines in clearing management
5. Optimum size and shape of clearings
6. Optimum percent of a management unit to devote to clearings and pattern of distribution of clearings
7. Determination of how much, where, and what kind of "edge" should be contributed by clearings
8. The degree to which animal use of agricultural clearings is an expression of need or preference
9. The extent to which agricultural clearings increase man-animal contacts.

RESEARCH NEEDS

The fact that significant decision-making areas concerning agricultural clearings in forest game management lie within the realm of inadequate information is a substantial demonstration of the need for research. These research needs, designed to meet specific problem areas regarding use of clearings, constitute the recommendations of this study. In addition, some of the findings of the study have implications for current game management programs. These are discussed in the Appendix.

Information is inadequate in four basic problem areas:

1. The need for base line information on existing range food resources (quantitative and qualitative) is pertinent to understanding: the possible supplemental food role clearings may play; the need for maintenance of expensive crops; the value of agronomic recommendations; the optimum size, shape, density, and distribution of clearings; and the need for added edge.

2. The need for reliable estimates of animal numbers is pertinent to all but the last of the areas listed in "1" and is also needed to better understand the role agricultural clearings play in game production, and the degree to which signs of animal use are indicators of preference or need.

3. The need for better animal behavior information is essential to understanding optimum size, shape, percent of area devoted to clearings, and distribution of clearings; what needs there may be for added edge; the degree to which animal use of clearings expresses need or preference; and to what extent agricultural clearings increase man-animal contacts.

4. Studies of hunter behavior are also needed to assess the role clearings play in man-animal contacts.

It is obvious that results from this research would not only provide needed information for evaluating agricultural clearings, but would at the same time provide the means for examining alternative management techniques. Up to this point, none but passing mention has been made of alternatives to the use of agricultural clearings, because they cannot be profitably evaluated either. To do so requires the same supporting research as is required to evaluate agricultural clearings.

Food Resource Information

The need for qualitative and quantitative base line information for food resources is a problem in wild animal nutrition. This study clearly establishes the link between provision of supplemental forage and agricultural clearings. Alternative management techniques may also include supplementing the food base. This is a problem area because information on animal needs and on the ability of native and domestic plants to meet these needs is very incomplete. Such information would provide the opportunity to manipulate the food base knowledgeably as a major game management tool.

Progress toward improved knowledge of game animal nutrition is being made, as illustrated by the nutrition papers in the Proceedings of the First National White-Tailed Deer Disease Symposium (1962). In addition, a great deal of data has been collected through food preference observations and stomach analyses. For example, Martin et al. (1951) have compiled such data and have assigned wildlife value ratings for many plant species. However, the decision to use an intensive habitat management tool such as agricultural clearings, with their associated crops and soil amendments, calls for nutritional data of a much more sophisticated nature than that now available. To make proper decisions about which crops, if any, should be grown and to what degree soil amendments should be added, will require information similar to that available to pasture farmers. The nutritional capacity of the range to support a given species or combination of species must be estimated before reasonable decisions can be made on what kind of, and to what extent, nutritional supplements are needed. Dietz (1965), for example, has recently discussed the problems of shrinking range and the need to relate nutrition research to deer-range management in the Western United States. Current information on game animal nutritional requirements is sparse, and each species has not been studied equally. Current means of estimating the animal carrying capacity of forested areas emphasize quantity and almost omit consideration of quality and availability of nutrients to the consumer.

From the viewpoint of animal requirements, the following are aspects in which significant contributions could be made:

1. Establishment and maintenance, through controlled breeding, of stocks of game as sources of experimental animals for pen nutrition studies

2. A critical review of the state of knowledge in this area aimed at delineating the significant gaps in information and suggesting means of improved coordination and contact among investigators in this relatively new field

3. Extension of pen nutrition studies to include additional game species plus the major subspecies of those animals now under study

4. Trials contrasting nutrient value of domestic plants to game animals as opposed to their established value to domestic animals (upon which we base current assumptions).

Regarding the problem of determining nutritional quality of a given range, the following study areas are worthy of consideration:

1. Studies of nutrient content and nutrient availability of native plants high on existing preference lists:

    a. Through the life of the plants or that fraction thereof during which they are available as game food

    b. In major ecological segments of the plant range

    c. Through annual seasonal changes within the plants.

2. Refinement of techniques used to measure carrying capacity by including consideration of nutrient availability as well as quantity.

An ultimate use of nutritional data will be the establishment of guidelines for conscious manipulations of the food base. Such control will consider such factors as:

1. Species composition
2. Age classes of food plants
3. Forage supplements
4. Soil amendments
5. Consequences of conscious and accidental disruption of the vegetative complex.

Population Estimates and Animal Behavior

In practice, animal behavior and estimation of animal numbers are interrelated. Behavior studies similar to that of Darling (1964) should be conducted in conjunction with studies on improved methods for estimating animal populations. Sampling designs suggested by the latter would be affected by the quality of behavioral information available. Davis (1963) points out several specific needs in this area:

1. The need to check current population estimating techniques against known numbers of animals
2. The need for additional basic methods
3. The need to express animal density in terms of the limiting factor rather than animal-per-acre.

New research tools, such as infrared photography, telemetry, isotope tracers, and automatic recording devices, should be fully tested and evaluated. Research of this nature is not suited to state game management agencies because by their very nature they are primarily concerned with short-term problems. University research centers or research institutes cooperatively financed by several state agencies may offer the best sponsorship.

Improved information on both nutritional requirements of animals and their behavior should open the way to significant studies of the effect of the interaction of these broad factors, and should give greater insight into relationships between free-living wild animals and their habitat.

Man-Animal Contacts

Availability of game depends upon the frequency of man-animal encounters. Habitat management can be regarded as having a potential for either bringing man to the game or the game to man. Clearings may have a baiting effect on game; and it is almost self-evident that roadways, trails, and clearings affect hunter distribution. If these are important factors, present techniques can be used to measure relative attractiveness rather easily. Such studies could measure and compare the attractiveness of areas under differing management to man and to game animals. Direct observation or mechanical recording techniques could be employed in appropriate sampling designs to contrast attractiveness of clearings and alternative management techniques under differing:

1. Cultural practices
    a. Crops
    b. Soil amendments
    c. Mechanical treatment of crops and soils
2. Weather conditions
3. Game seasons
4. Degree of accessibility
5. Location and dispersion of managed areas
6. Time durations of hunting.

Frequently, game managers have expressed the opinion that hunter distribution is important. This is an area open to fairly easy, short-duration studies. The public is now accustomed to cooperating with field research efforts, and it should not be difficult to establish experimental areas where users would record their preferences (an index to attractiveness) between management areas. They might record and hand in accounts of their activities among the areas under contrast. Museums have sampled visitor preference and interest among exhibits through use of automatic voting machines borrowed from local officials. Adaptations of these techniques could sample user preference and differential use of management units. Certainly, techniques used in recreation research could be adapted to this use.

An ultimate goal is to study possible relationships between user activity and game distribution, as influenced by management techniques, when much improved measures of animal numbers and movements are available.

Additional Needs

In addition to the research recommendations, there are two aspects where effective contributions could be made. Soil mapping of forest land with the same intensity as that applied to agricultural land has potential value for forest-wildlife management programs which should be fully explored. Pilot areas on a few National Forests have been mapped and provide an opportunity for studies to determine how this new information may be applied in wildlife habitat management.

Steps should be taken to provide increased opportunities for habitat managers from the various states to meet frequently and to discuss and evaluate progress and problems. Many of the diverse opinions and practices concerning use of agricultural clearings appear to have evolved in the absence of opportunity to share ideas and problems among the states and federal agencies. Because established regional meetings usually have full programs oriented toward animal management, perhaps the various colleges and university departments of wildlife instruction could act as host for annual regional meetings of habitat managers and develop a series of summer short courses similar to those offered to workers in agricultural fields. Such meetings could improve communications and promote frequent evaluation of habitat management practices.

A cursory review of these conclusions and recommendations indicates that no strikingly new suggestions have been presented. Many of these ideas were discussed at the outset of this study; and it has been shown that the major needs for research, especially improved techniques for estimating animal numbers, have been pointed out as major research needs by others.

During the initiation of this study, the writer was presented with a host of suggestions and possible directions to follow in establishing a better understanding of the use of agricultural clearings in forest game management. With few exceptions these were varied concepts originating with persons well trained in the wildlife management field or with persons who had many years of practical management experience, or both. To these were added concepts from persons in more than 20 states. Some had been published, many were found in unpublished files, and a significant number were suggested by persons who had considerable personal experience with agricultural clearings and had taken time to think about various problems they had encountered.

At the outset, any set of conclusions could be well advanced and all had equal weight--as far as the writer could determine. At the same time, few professional people felt able to make recommendations which would have broad application wherever agricultural clearings were used. Drawing on the strength of the first critical review of the clearing practice, this study has evaluated the array of independent conclusions and offers a series of documented and coordinated conclusions applicable to the use of clearings regardless of location. It has documented the need for behavior, nutrition, and population estimation research for this specific problem area, and has shown through a series of recommendations the pertinence of each with respect to answering current management needs. In a broad sense, this study fills a gap in knowledge by selecting the appropriate set of research needs from a broad repository of recognized needs for knowledge and identifies them with, and applies them to, a critical management problem area.

APPENDIX

Guides for Interim Management Procedures
Pending Improved Knowledge

The hypothetical game manager who is given 10,000 acres of eastern forest land to manage for maximum production and availability of game must make many decisions in designing his management plan. He must weigh many management techniques currently in vogue in the light of the ecological condition of his area and the ability of various techniques to meet the problems which impede local production and availability of wildlife. Ideally, he should make initial inventories of animal and plant populations, determine limiting factors, and plan for management accordingly. In reality, he will most likely be given the management area and one year's inadequate budget and told to make the best of it and to show definite improvement in 12 months. It is within this context of practicality that management guidelines must be offered. The average manager or state game agency cannot wait for sophisticated research, but must provide a service today and modify decisions in the light of more knowledge later. It is to minimize the inevitable unhappy consequences of this condition that the following guidelines for management are rather closely restricted in scope.

Agricultural clearings, and the related system of roads and access ways necessary for their construction, make a positive contribution toward game management in two well-founded ways:

A. As a means of providing access in areas not already open
  1. Management access
  2. User access
  3. Protection access
    a. Law enforcement
    b. Fire protection
  4. Access for multiple use
    a. Forest management
    b. Nongame-related recreation

B. As a means of adding diversity to the vegetative habitat
  1. Openings in the forest for roads and access ways
  2. Openings and changes for multiple use
    a. Timber removal and stand improvement
    b. Trails and campsites
  3. Actual creation and management of the agricultural clearings themselves.

Pending further research on supplemental food values, influence on animal numbers and distribution, and improved means of estimating numbers of animals, attempts to provide guidelines outside of the topics of access and increased vegetative diversity lack sufficient foundation. Likewise, programs which are based on assumptions beyond the factors of access and simple manipulation of vegetative diversity can be challenged.

If the hypothetical management area is essentially roadless, the question of access is one which may have no relation to agricultural clearings. On the other hand, if the area is deemed lacking in diversity to the extent that herbaceous openings are needed in number, roads may be required first. Under most circumstances, long-range multiple-use management plans will absorb most of the cost of roads and road maintenance in a variety of desirable activities, and thus the portion of these costs to wildlife will be proportionally small. The fact still remains that there have been areas where wildlife funds, as such, have paid for all initial costs of roads plus clearings; and multiple use followed in later years. At any rate, the opportunity is available to use multiple justification for road building and maintenance.

The creation of a road system alone meets all of the access requirements of "A," plus the diversity in habitat under "B-1." With the addition of multiple-use activity, all access and all aspects of vegetative diversity are met except the diversity created by clearings themselves. Because all costs of creating and maintaining agricultural clearings themselves, plus any spur roads added to the road system, must be wholly borne by wildlife interests, this is the crucial point of decision for the manager. The decision at this point must currently be based on the necessity for added diversity, or for adding an essential element necessary for successful game management of the area.

Two special elements other than increased diversity warrant consideration. Management units designed to serve primarily as suppliers of game for live-trapping and restocking in other areas may be the backbone of a wildlife restoration program of a state. As such their cost should be prorated over an indefinite period of time. The units themselves are usually phased out of this activity when the game restocking program is completed. Use of agricultural clearings to supplement the basic food supply and to attract animals to suitable baited trapping locations is probably justified in such cases, assuming that they have a definite life span as a special purpose area. The other element to consider is the demand for suitable areas for bow hunting. This specialized sport requires opportunities to harvest game on open areas free of interference to the arrow. In every state which permitted bow hunting, and on the Patterson Creek Study Area in Virginia, the writer was impressed by the dependence bow hunters had for sod clearings on which to hunt. How far any management plan can justify catering to this group of hunters is impossible to judge except under local conditions.

Aside from these special considerations, the writer believes that few cases will justify creation of new agricultural clearings for added diversity alone; given forest management as a related activity on the area, diversity itself can be created over larger areas at less expense in other ways. Exceptions are possible and the extensive plantings of conifers in areas such as occur on the Piedmont in South Carolina may be one example. Such a manmade or man-maintained environment may so limit diversity that any opportunity to support a huntable population of turkeys, for example, without periodic breaks in a solid conifer canopy to allow vegetation to grow which will support an insect food supply is precluded. Such examples will be the exception and at the present state of knowledge the concept that more diversity means more game cannot be extended beyond the most general terms, as far as forest game is concerned.

The foregoing discussion pertains mostly to the manager facing a previously unmanaged tract of land. For the many circumstances where clearings are an established fact, the writer recommends the following approaches. These are based on recognition of the fact that existing clearings represent an investment to be respected and that in some areas practical public relations factors may be more influential than biological facts.

1. Present clearings should be maintained as openings insofar as practical and consistent with other land-use demands. These clearings represent substantial expenditures and, as areas of open land, offer better opportunities for future habitat manipulation than do forested sites.

2. Limit maintenance to as little periodic rotary mowing as is necessary to keep woody succession out--probably once every 2 or 3 years.

3. Limit soil amendments to a level of topdressing which will cause the clearings to become somewhat more attractive than an untreated site. This will vary from area to area, but probably should not be more often than once every 2 years. A minimum of fertilizer and lime should be applied. This recommendation should be eliminated if the mowing alone keeps the site more attractive than otherwise.

In summary, pending improved information, the game manager should exercise extreme caution regarding commitment to an expensive program of agricultural clearings. Too little is known about many of the assumptions which have evolved with the use of agricultural clearings to make further specific recommendations to the land manager.

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Sampling Procedures for Estimating Mass and Dispersed Types of Recreation Use on Large Areas

by

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and

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Sampling Procedures for Estimating Mass and Dispersed Types of Recreation Use on Large Areas

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The objective of this study was to pilot test a sampling model for estimating the amount and kind of recreation use, both mass and dispersed, that occur on large forest areas. Other investigators[1 2 3] have tested sampling models for estimating dispersed recreation use on large areas, but their efforts were directed at estimating current use only. No provision was made for testing relationships between use and some related indicator on which use estimates might be revised in future years. The procedures described in this report can be used to estimate use from traffic-counter records for a 3- to 5-year period following the calibration year.

The sampling model was tested during summer 1966 on the Pacific District, Eldorado National Forest in California (fig. 1). The Pacific District is situated on the west slope of the Sierra Nevada Range, just west of Lake Tahoe and approximately 65 miles east of Sacramento. The District boundary encompasses 195,000 acres, of which 130,000 acres are National Forest and 65,000 acres are private land. Elevation varies from 2,300 feet to 10,000 feet. With more than 200 miles of streams and many lakes and reservoirs that are easily accessible, the District is a popular area for water-oriented recreation. Several important trails to the Desolation Valley Primitive Area originate on the District.

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[1] Lucas, Robert C. The recreational use of the Quetico-Superior Area. Lake States Forest Exp. Sta., U. S. Forest Serv. Res. Pap. LS-8, 52 pp., illus. 1964.

[2] Cushwa, Charles T., McGinnes, Burd S., and Ripley, Thomas H. Forest recreation estimates and predictions in the North River Area, George Washington National Forest, Virginia. Va. Polytech. Inst. Agr. Exp. Sta. Bull. 558, 48 pp., illus. 1965.

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The sample was taken in accordance with a stratified random-sampling technique, which we labeled "cordon sample," because it involved checkpoints on roads at or near the District boundaries. We interviewed recreationists as they left the area to determine their length of stay within the District and the types of recreational activities they pursued. In addition, four developed sites, which received heavy use, were sampled independently in accordance with a regression sampling technique as described later.

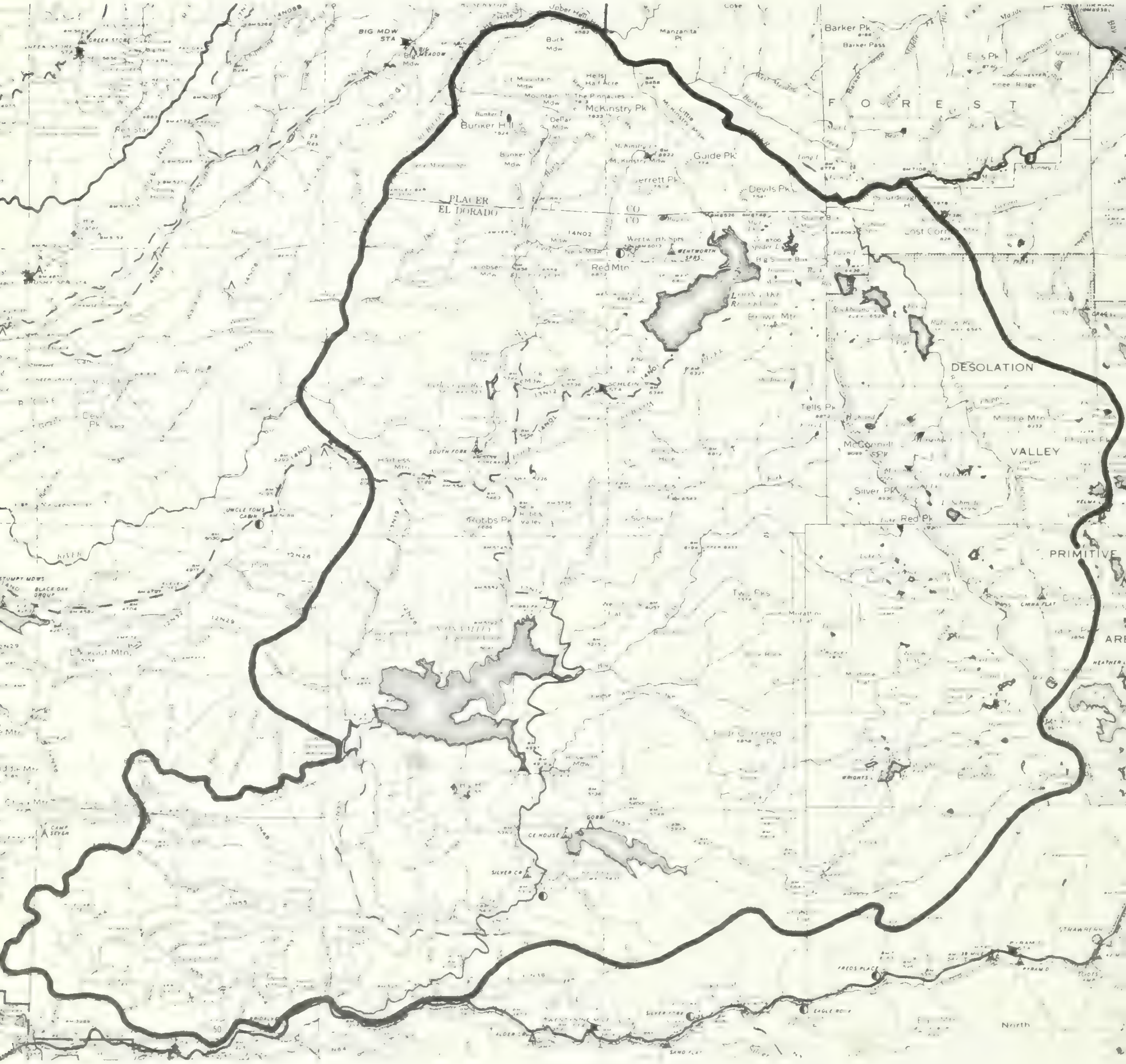

Figure 1.--Recreation sites and road network on the Pacific District, Eldorado National Forest, California.

The recreation season for which use estimates were generated included the peak season from June 13 to September 5, and the first 2 weeks of hunting season from September 23 to October 8, 1966, inclusive, for a total season of 101 days.

Before the study was started, all exit roads were examined and classified according to the amount of use they were expected to receive during the sampling period. The exit classes were based on knowledge of past use as follows: Class A, high-expected use; Class B, moderate-expected use; and Class C, low-expected use. On this basis, the study included 3 Class A, 4 Class B, and 27 Class C exits.

Two of the six trails to the Desolation Valley Primitive Area were randomly selected and included in the sample; but the exits for the developed sites, which were sampled independently, were not included. All exits included in the sample were identified and labeled by class on a detailed map of the District.

Interviews were conducted on a total of 20 days during the 101-day recreation season--10 randomly selected weekdays and 10 randomly selected weekend days or holidays. Each of the selected sampling days was then randomly paired with one of the exit points in each of the three exit classes.

For example, let's assume that Wednesday, June 29, was the first randomly selected day. Random selection would then be made from each of the three exit classes, resulting--perhaps--in the selection of exits 2-A, 4-B, and 26-C. On June 29, therefore, interviewers would be assigned to each of these exit points for the full 12-hour sampling day, from 8 a.m. to 8 p.m.

Vehicle counts were obtained mechanically during the recreation season to establish relationships between use, by activity, and traffic on which use estimates might be revised in future years. These counts were obtained by using permanently installed printout-type counters in "key" locations within District boundaries; two located at a Class A exit (Ice House Road), and two at a Class B exit (Wrights Lake Road).

At each location, a counter was placed on each lane to obtain separate records for entering and exiting traffic. In addition, small pneumatic-tube, direct-reading-type counters were placed alongside each printout-type counter as a check. In selecting roads on which to place traffic counters, consideration was given to representativeness of location, distance from headquarters or supervisory personnel as it would influence relative ease of counter reading and servicing requirements, and needs of Forest Service engineers for highway traffic-count information.

The Ice House Road was heavily traveled by logging trucks. So that we could base our final analyses on recreation traffic only, we obtained a detailed record of this nonrecreation traffic from the Forest Service log-scale station located on the Ice House Road near the south entrance to the District.

The position of each interview checkpoint was chosen carefully to minimize hazards to motorists and interview personnel. Checkpoints were not established at road exits where vehicle speeds were normally high. In these cases, checkpoints were established along secondary road exits leading onto high-speed roads. These checkpoints generally were not located near District boundaries. Three portable "caution" signs were erected at established checkpoints on Class A and Class B exits. A sign advising motorists to reduce speed was placed approximately 100 yards on each side of the interview checkpoint. A stop sign, facing traffic leaving the area, was erected at the checkpoint. Caution signs were not needed on Class C exits because this traffic was generally moving slowly. All signs were made according to State Highway Department specifications and covered with reflective material to insure better visibility. As a precautionary measure, a battery-powered, yellow blinker light was placed on each caution sign.

Forest visitors were most cooperative during the study. Not one party out of almost 3,000 who stopped at the check stations refused to be interviewed. Only seven motorists failed to stop at the recreation check station.

The driver of each exiting vehicle was requested (by sign) to stop at the checkpoint. The purpose of the study was then briefly explained to the occupants of the vehicle and a request made that each head-of-household answer a few nonpersonal questions concerning the time they spent on the District. It was further explained that the information obtained was to be used for statistical purposes only, in combination with data from other respondents. Questionnaires were completed only on those visitors leaving the District. The questionnaire and Form 2.0 (Appendix) were used to determine, by household, total hours of use (recreation and nonrecreation) and kind of recreational activity pursued on Forest Service land and on private inholdings within Pacific District boundaries.

Four seasonal employees were trained to conduct the sampling and to service the traffic counters. In addition, several permanent Forest Service employees were also trained in the event that additional help was needed during busy periods. On a few occasions, three interviewers were needed on certain Class A exits.

The cordon-sampling technique was designed to yield estimates concerning how much and what kind of use occurred on the Pacific District during the 101-day recreation season. Other than indicating that use occurred either on developed sites or in the general forest area, and on Forest Service land or on private inholdings within District boundaries, the information collected does not indicate precisely where this use occurred.

Recreation planners also need to know where, specifically, important segments of use occur. A second sampling technique[4] was therefore employed to estimate use on four important, developed sites that receive heavy use on the Pacific District. The sites included Ice House Campground, Gobi Campground, Ice House Boating Site, and Wrights Lake Campground. Ice House Campground, Gobi Campground, and Ice House Boating Site comprise a developed site complex served by one entrance.

Use estimates were generated, using the "double-sampling" technique, by establishing relationships between the desired statistic (use by activity, total use) and traffic counts. Use and traffic counts were simultaneously measured on 12 randomly selected days during the period June 13 to September 5, 1966. Half of the samples were taken on weekdays, and half on weekend days and holidays. Each sampling day was 12 hours in length, from 9 a.m. to 9 p.m. Two direct-reading, pneumatic-tube traffic counters were placed at the entrance to the Ice House Campground complex, and two at the entrance to Wrights Lake Campground.

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[4] James, George A. Instructions for using traffic counters to estimate recreation visits and use on developed sites. U. S. Forest Serv. Southeast. Forest Exp. Sta., 12 pp., illus. 1966.

This sampling technique has been used to estimate recreation use on several hundred Forest Service developed sites since 1963. Full details concerning its use are found in the publication listed above. Although it was originally a double-sampling technique, through modification it is now a regression technique. It has become widely known as the double-sampling technique, however, and for this reason will be referred to by this name throughout the report.

A limit of trout from Union Valley Reservoir. Fishing accounted for over 18,000 visitor-days of use on the Pacific District.

ANALYSIS AND RESULTS

Use data obtained by interview, and recorded on Form 2.0, were edited and punched onto ADP cards to facilitate machine processing. A total of 2,973 completed questionnaires on heads-of-household were used in the analysis.[5] Use estimates and sampling errors were determined by regression analysis for 37 activities occurring on Forest Service land within District boundaries and for 33 activities occurring on "other" land within District boundaries. Activities (Y variables) were regressed on several combinations of traffic count (X variables) obtained at the two counter locations to determine which location produced the strongest correlations. The "X" variables used included:

Ice House Road Traffic	Wrights Lake Road Traffic
12-hour traffic (ENTERING)	12-hour traffic (ENTERING)
12- " " (EXITING)	12- " " (EXITING)
24- " " (ENTERING)	24- " " (ENTERING)
24- " " (EXITING)	24- " " (EXITING)

Ice House Road and Wrights Lake Road Traffic Combined

12-hour traffic (ENTERING)
12- " " (EXITING)
24- " " (ENTERING)
24- " " (EXITING)

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[5] The time an interview began and ended was recorded for each completed questionnaire. The average time for all interviews was $1\frac{1}{2}$ minutes. This value, however, also included nonrecreation use by drivers of logging trucks. Logging trucks were generally requested to stop only on their first trip on each sampling day to determine average round-trip time. Then throughout the remainder of the day they were waved through the checkpoint without being stopped. The average recreation interview time, therefore, was probably close to 3 minutes.

Success of the pilot test was dependent upon strong correlations between use and traffic patterns at one or both of the selected counter locations. The analysis revealed that the strongest relationships occurred between use, by activity, and traffic registered at the counters on Ice House Road. All combinations of counter readings on Ice House Road gave acceptable correlations, but the 24-hour exiting values produced the strongest relationships. Traffic patterns at Wrights Lake Road were weakly correlated with recreation use over the Pacific District.

Use estimates, confidence intervals, and linear regression formulae (based on 24-hour exiting traffic at Ice House Road) are shown in table 1. Relationships between traffic count and important high-use recreational activities which occurred on Forest Service lands were relatively strong. As expected, relationships were generally weak between traffic count and most low-use activities. This was especially true for all activities which occurred on "other" land within District boundaries. Table 1 does not include data by activity on "other" land because use was light, and activity estimates were associated with wide confidence intervals. Wide confidence intervals indicate that use is highly variable and that sampling intensity must be increased if more precise estimates are desired. The relative unimportance of many of the low-use activities which occurred on all land within Pacific District boundaries does not warrant increased sampling intensity.

Total estimated recreation use on the Pacific District during the 101-day use period was 165,961 visitor-days. This does not include estimated use at the four developed sites that were sampled separately. Almost 93 percent of total use occurred on Forest Service land, and 7 percent occurred on "other" land within District boundaries. Of all recreation use, 35 percent occurred on weekdays and 65 percent on weekend days and holidays.[6] Ninety-seven percent of the vehicles that stopped at the recreation check station were from California.

Regression analysis was also used to generate estimates of use for Ice House Campground, Gobi Campground, Ice House Boating Site, and Wrights Lake Campground. Estimates, confidence intervals, and linear regression formulae are shown in table 2 for these sites.

Use estimates for the important, heavy-use activities occurring at Ice House Campground and Wrights Lake Campground were quite precise, indicating reasonably strong relationships between use and traffic count. Fairly weak correlations apparently exist between use and traffic count at Gobi Campground and Ice House Boating Site. The probable reason is that these two sites are served by a common entrance that serves three developed sites. Traffic using this single entrance is more strongly associated with use at Ice House Campground than with use at Gobi Campground and Ice House Boating Site. All use estimates are valid, of course, even though some are associated with relatively wide confidence intervals.

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[6] Day-of-week estimates were generated using stratified random-sampling analytical procedures.

Table 1.--Estimates of use on National Forest land, Pacific District, Eldorado National Forest, California, June 13 to September 5 and September 23 to October 8, 1966, inclusive[1]

Activity	Use estimate	Confidence interval[2]	Regression formula[3]
	Visitor-days[4]	Percent	$Y = a(N) + b(X_S)$
Night use (developed sites)	19,418	21.2	$-193.1379(N) + 0.6973(X_S)$
Night use (dispersed areas)	25,300	29.6	$-115.9952(N) + 0.6631(X_S)$
Night use (motel, hotel)	0	--	--
Night use (recreation residence)	7,537	24.2	$-55.6471(N) + 0.2357(X_S)$
Night use (organization camps)	1,273	58.0	$0.3883(N) + 0.0221(X_S)$
General activity, vicinity overnight quarters	14,471	19.1	$-72.1588(N) + 0.3898(X_S)$
Picnicking (developed sites)	1,637	63.9	$8.8572(N) + 0.0133(X_S)$
Picnicking (dispersed areas)	1,636	24.5	$6.3019(N) + 0.0179(X_S)$
Fishing	18,014	15.8	$52.7308(N) + 0.2273(X_S)$
Boating, power	1,110	25.9	$10.8781(N) + 0.0002(X_S)$
Boating, nonpower	1,075	29.1	$5.7230(N) + 0.0089(X_S)$
Swimming (developed sites)	0	--	--
Swimming (dispersed areas)	5,842	29.8	$41.4786(N) + 0.0296(X_S)$
Watching activities on water	295	43.8	$2.7598(N) + 0.0003(X_S)$
Watching activities on land	285	63.6	$-3.5880(N) + 0.0116(X_S)$
Nature study	142	40.8	$-0.7467(N) + 0.0039(X_S)$
Gathering products	697	17.2	$-2.4954(N) + 0.0170(X_S)$
Team sports (developed sites)	11	85.0	$0.1676(N) + (-0.0001)(X_S)$
Team sports (dispersed areas)	52	75.8	$0.6228(N) + (-0.0002)(X_S)$
Hunting (all types)	8,318	40.6	$-235.2774(N) + 0.5747(X_S)$
Viewing exhibits	0	--	--
Road travel (motor)	6,704	15.5	$-44.7726(N) + 0.2011(X_S)$
Road travel (nonmotor)	94	43.0	$-0.3388(N) + 0.0023(X_S)$
Trail travel (motor)	892	39.1	$-22.9999(N) + 0.0576(X_S)$
Trail travel (nonmotor)	7,623	37.4	$-6.0483(N) + 0.1475(X_S)$
Off road and trail travel (motor)	46	39.0	$-1.8065(N) + 0.0041(X_S)$
Off road and trail travel (nonmotor)	3,295	35.1	$15.7100(N) + 0.0306(X_S)$
General leisure	4,497	21.9	$3.0711(N) + 0.0750(X_S)$
Undifferentiated recreation use	22,719	17.4	$5.3555(N) + 0.3973(X_S)$
Nonrecreation use	43,876	23.0	$518.2045(N) + (-0.1516)(X_S)$
Total use (recreation and nonrecreation)[5]	209,837		

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[1] Does not include use which occurred on Ice House Campground, Gobi Campground, Ice House Boating Site, and Wrights Lake Campground.

[2] Confidence interval at the 67-percent level of probability, expressed as percent of the estimate. Example: If estimated season-long camping use is 30,000 visitor-days for a given sample, and the confidence interval is ± 10 percent at the 67-percent level of probability, we construct the interval 27,000-33,000 visitor-days. On the average, 67 percent of such intervals will include the true value if we sample an unlimited number of times.

[3] Of the form $Y = a(N) + b(X_S)$, where "a" and "b" are constants, N is number of days in sampling season, and X_S is season-long axle count.

[4] Recreation use which aggregates 12 person-hours. May entail 1 person for 12 hours, 12 persons for 1 hour, or any equivalent combination of individual or group use, either continuous or intermittent.

[5] Includes 12,978 visitor-days of recreation use that occurred on "other" land within Pacific District boundaries. See example on page 14 for regression formula.

Table 2.--Estimates of recreation use at four developed sites on the Pacific District, Eldorado National Forest, California, June 13 to September 5, 1966, inclusive

Site and activity	Use estimate	Confidence interval	Regression formula
	Visitor-days[1]	Percent[2]	$Y = a(N) + b(X_S)$
ICE HOUSE CAMPGROUND[3]			
Total use, all	13,298	14.8	-31.83(N) + 0.2821(X_S)
Picnicking	100	28.3	1.31(N) + (-0.0002)(X_S)
Camping	13,107	15.3	-32.55(N) + 0.2798(X_S)
Viewing scenery	92	33.7	-0.49(N) + 0.0024(X_S)
GOBI CAMPGROUND[3]			
Total use, all	2,718	32.2	-70.72(N) + 0.1538(X_S)
Picnicking	219	26.4	2.02(N) + 0.0008(X_S)
Camping	2,405	39.1	-72.66(N) + 0.1512(X_S)
Team sports	6	58.8	0.15(N) + (-0.0001)(X_S)
Viewing scenery	91	36.9	0.34(N) + 0.0011(X_S)
ICE HOUSE BOATING SITE[3]			
Total use, all	855	32.8	-22.83(N) + 0.0493(X_S)
Picnicking	83	85.3	0.44(N) + 0.0008(X_S)
Camping[4]	414	72.8	-23.37(N) + 0.0423(X_S)
Swimming and bathing	4	130.6	0.00(N) + 0.0001(X_S)
Powerboat launch	58	47.1	-1.87(N) + 0.0038(X_S)
Nonpowerboat launch	20	84.4	-0.76(N) + 0.0015(X_S)
Viewing scenery	276	24.1	2.72(N) + 0.0008(X_S)
WRIGHTS LAKE CAMPGROUND			
Total use, all	11,812	15.4	71.68(N) + 0.1189(X_S)
Camping	11,663	15.7	70.58(N) + 0.1178(X_S)
Tours, guided and unguided	11	106.8	0.19(N) + (-0.0001)(X_S)
Viewing scenery	131	29.5	0.82(N) + 0.0013(X_S)
Horse (horseback riding)	7	56.0	0.10(N) + 0.0000(X_S)

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[1] Recreation use which aggregates 12 person-hours. May entail 1 person for 12 hours, 12 persons for 1 hour, or any equivalent combination of individual or group use, either continuous or intermittent.

[2] Confidence interval at the 67-percent level of probability, expressed as percent of the estimate.

[3] A developed site complex consisting of Ice House Campground, Gobi Campground, and Ice House Boating Site. All sites are served by one entrance.

[4] The Ice House Boating Site parking lot was used as an overflow area for campers when Ice House Campground and Gobi Campground were full.

Wide confidence intervals reveal that use was highly variable, and that sample size was not large enough to produce more precise estimates.

A summary of estimated recreation use which occurred on the Pacific District during the 101-day sampling period is as follows:

	Visitor-Days
Ice House, Gobi, and Wrights Lake Campgrounds, and Ice House Boating Site (June 13 - September 5, 1966)	28,683
All other use (June 13 - September 5, and September 23 - October 8, 1966)	165,961
Total	194,644

Recreation use that occurred before and after the periods included in the sampling season must be added to produce yearlong estimates for 1966.

Union Valley Reservoir, one of the many attractions on the Pacific District. This beautiful body of water received heavy recreation use.

DISCUSSION

The primary objective of the pilot study was successfully met. The study resulted in a useful sampling tool for obtaining estimates of current recreation use, with provision for generating short-term estimates based on an easily obtained indicator of use. The "updating" feature is of considerable importance because it materially reduces overall sampling costs. The sampling procedures should be useful to all public agencies where the need for reliable recreation use estimates is increasing rapidly.

Cost of the pilot study was $15,960 for all field-sampling phases and approximately $1,000 for analyses and report preparation. A detailed cost record is shown below:

Cordon sample	
Wages (includes traffic-counter checks)	$ 3,485
Training	1,830
Administration	1,680
Mileage (including admin. and training)	600
Traffic counters and installation	4,160
Signs and miscellaneous equipment	470
Computer service for traffic counts	90
	$12,315
Double samples	
Wages (includes traffic-counter checks)	$ 1,480
Training	540
Administration	360
Mileage (including admin. and training)	200
Traffic counters	200
Miscellaneous	25
	$ 2,805
House-trailer purchase and pad rental[7]	$ 840
Analyses and report preparation	
ADP computer costs	$ 350
Wages	650
	$ 1,000
Total	$16,960

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[7] No housing was available for the interviewers on the Pacific District. To avoid excessive travel between nearest housing and the work area, a trailer was maintained in a centralized location within District boundaries for their use.

The full purchase price of equipment should not be charged to the study because traffic counters,[8] trailer, and signs are no longer needed for sampling purposes and can be used elsewhere. Using a conservative life expectancy figure of 5 years for this equipment, a "credit" of approximately $3,250 can be made, bringing total cost down to $13,710. Assuming that relationships between use and traffic pattern remain constant for several years, and estimates can be updated annually for another 4 years; average annual cost becomes approximately $2,750. To this must be added an annual cost of perhaps $250 for administration, travel associated with traffic-counter maintenance, translation of traffic-counter record, and preparation of use estimates.

The price tag on the 1966 pilot test was considerably higher than the cost of "repeat" sampling efforts would be. In an effort to make the pilot study succeed, more time than was actually necessary was devoted to training, administration, and traffic-counter servicing. The six counters used on the cordon-sampling phase could have, quite safely, been reduced to two. The considerable trouble encountered in final traffic-counter installation added several hundred dollars to cost. Other savings could also have been effected.

The sampling plan was revised in line with experience gained during 1966 on the Pacific District, and a second cordon sample was conducted during the summer of 1967 on the Bridgeport District, Toiyabe National Forest, Nevada-California. Sampling intensity has been reduced 25 percent, only one traffic counter has been installed, and all other costs have been reduced substantially. It is expected that total cost for this sampling effort will be approximately $7,500. Prorated over a 5-year period, annual costs should be about $1,500.

The following important steps and precautions are offered for those who might be interested in using the technique:

1. The basic assumption underlying the "updating" procedure is that relationships between traffic patterns and usage will remain relatively constant for several years. The technique should be used, therefore, only on recreation sites and areas where major change, such as substantial expansion of forest recreation areas or construction of reservoir or super highway within or near area boundaries, is not likely to occur within a 3- to 5-year period following the calibration period. Where major change takes place, it is likely that regression formulae developed during the calibration year may not be valid after the change or changes take

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[8] All traffic counters on the Wrights Lake Road, and all but one counter on the Ice House Road, may be removed and used elsewhere. The only counter needed is one on Ice House Road to obtain a complete record of exiting traffic for the next several years. In addition, counters are needed at the entrances to Ice House Campground and Wrights Lake Campground.

place. To detect any changes that might act to confound the basic assumption, some periodic followup sampling is recommended. A much smaller sample every third year would act as a "sensor" to detect changes in the character of traffic flow-visitor use relationships.

2. Stratification of exits into "expected volume of use" classes must be done carefully. In general, the more precisely this job is done, the more precise will be all estimates of use.

3. The traffic counter (or counters) must be installed at a "key" location, representative of recreation use over the entire area. This location will usually be a high-use road, of any ownership class, on or near the area boundary. If the key road also carries heavy commercial traffic, such as logging trucks, traffic counters of the type which separately records passenger vehicles and heavy commercial vehicles must be installed. The other solution, such as was the case on the Pacific District, is to obtain a complete record of logging trucks using the road.

   Traffic counters must be properly installed and checked frequently to insure a complete, unbroken, season-long traffic record.

   The network of highways on which traffic-flow patterns are being studied by Federal, State, and County agencies is increasing each year. Where such records are available for roads on or near recreation areas, it may not be necessary to purchase and install counters for sampling purposes. In other cases, counter and installation costs might be shared with other divisions or agencies.

   Traffic counters should be ordered well in advance to insure that they are installed and working satisfactorily prior to study initiation. A 5- to 6-month advance order is recommended.

4. Federal agencies planning to obtain use estimates by interview must obtain advance approval from the Bureau of the Budget before questionnaire sampling can be initiated.

The sampling technique described in this report constitutes an important step forward, but the claim is not made that it is the final answer. A continuing effort will be made to design and test new and improved sampling techniques to provide recreation administrators with useful tools for obtaining accurate and inexpensive estimates of recreation use.

APPENDIX

USE OF REGRESSION FORMULAE FOR CALCULATING AND UPDATING USE ESTIMATES

For several years following calibration, the only information needed to update all use estimates is an accurate traffic-count record obtained at each of the indicator locations and covering the same dates used during calibration. Estimates of use on the Pacific District, obtained by cordon sampling, can be updated by incorporating a record of vehicles (axles) that leave the District through the south exit on Ice House Road during the period June 13 to September 5 and September 23 to October 8, inclusive. Estimates of use on the four developed sites that were double-sampled can be updated by incorporating traffic-count records obtained at the entrances to the respective sites during the period June 13 to September 5, inclusive.

Example

The formula for obtaining an estimate of total recreation use on "other" lands within District boundaries is:

Y (Total recreation use on "other" lands within District boundaries) = $a(N) + b(X_s)$, where "a" and "b" are constants, N = number of days in the sampling season, and X_s = season-long axle count.

$= -258.4464(101) + 0.7001(55{,}822 \text{ axles})$

= 12,978 visitor-days

To estimate amount of use that occurred on "other" lands within District boundaries during the 1967 (and later) recreation season, incorporate a new season-long axle count for a similar 101-day period and solve the formula.

CORDON SAMPLING TO ESTIMATE MASS AND DISPERSED RECREATION USE

Pacific District — Eldorado National Forest
6/13/66 - 9/30/66

(To be completed by interviewer)

Record on
Form 2.0
(Column No.)

1. Determine number of households represented. (May be obvious. Ask only when necessary.)

2. When (month, day, and hour) did you, or you and the household (or organization) members you represent, enter this area? Time and date refers to last entry onto District. 12, 13, 14

3. Did you (and your party) participate in recreation? 16

IF NO, END INTERVIEW IF ALL TIME WAS SPENT IN COMMERCIAL, RESIDENTIAL, OR OTHER NONRECREATIONAL ACTIVITY.

IF YES, PROCEED TO NEXT QUESTION.

4. How much total time did you, or you and the party you represent, spend at Ice House and Wrights Lake? (Names of developed sites that are being double sampled.) 17, 18

ASK QUESTION NUMBERS 5, 6, 7 ONLY IF RESPONSE TO NUMBER 4 INDICATES THAT EXISTING PARTY STAYED OVERNIGHT WITHIN THE DISTRICT BOUNDARY.

5. How many person nights were spent in the following types of quarters? (Number of nights multiplied by number of persons represented.)

   a. Temporary shelter (such as tent, trailer, etc.) on developed sites. 19
   b. Temporary shelter (as above) on dispersed areas. 21
   c. Hotel, lodge, resort, or motel. 23
   d. Recreation residence. (Summer home.) 25
   e. Organization camp. 27

6. On the average, how many hours per night (8P - 8A) did your party spend in or in the immediate vicinity of the shelter or quarters? (as appropriate, 20, 22, 24, 26, 28)

7. How many daylight hours did you, or you and the party you represent, spend in activities such as relaxing or preparing and eating meals, in:

(The immediate vicinity of the developed campground)

(Within approximately 200 yards of where you pitched your tent or parked your trailer on dispersed areas) 29

(Within the buildings and/or on the grounds of hotels, lodges, resorts, and motels, recreation residences, and organization camps?)

8. How much time was spent in activities such as relaxing, and preparing meals, on or in the immediate vicinity of the place where picnic meals were consumed, including time spent consuming meals?

   a. On developed sites. 30
   b. On dispersed areas. 31

9. How much total time was spent in the following activities?

ASK ONLY QUESTIONS PERTINENT TO SEASON AND ACTIVITY OPPORTUNITIES KNOWN TO EXIST ON THE DISTRICT.

   a. Fishing (night or day from boat, dock, pier, etc.) 32
   b. Boating, power (excluding fishing, but including travel). 33
   c. Boating, nonpower (excluding fishing, but including travel). 34
   d. Swimming and water sports (on dispersed areas) 36
   e. Watching recreation activities on water. 37
   f. Watching recreation activities on land. 38
   g. Nature study, natural history and science, works of man, etc. 39
   h. Gathering forest products. 40
   i. Participate in team sports and play on developed sites (includes football, archery, target practice, etc.) 43
   j. Participate in team sports and play on dispersed areas (see question 9i. 44
   k. Hunting (all forms, including noncommercial trapping). 45
   l. Exhibits, tours and programs (participation in or use of visitor service provided by the Forest Service). 46
   m. Travel (including brief stops along roadside or trailside).
      (1) Road travel, motor. 47
      (2) Road travel, non-motor (includes hiking and horseback). 48
      (3) Trail travel, motor. 49
      (4) Trail travel, nonmotor (includes hiking and horseback). 50
      (5) Off-road or off-trail travel, motor, 51
      (6) Off-road or off-trail travel, nonmotor. (includes mountain climbing, hiking and horseback). 52
   n. General leisure and sightseeing away from camp or picnic site (miscellaneous). 5[illegible]

(30) (31) - On developed sites means any developed site. Dispersed area means any dispersed area element of the recreation population. Response is to yield activity 43.1 (Picnicking).

(32) - Response is to yield activities 31.1 (Fishing, cold water), 31.2 (Fishing, warm water), 31.3 (Fishing, salt water).

(33) - Get activities 12.1 and 12.2, which are Boating and Cruising in a variety of powered craft.

(34) - Get activities 15.1, 15.2, and 15.3, which are Boating in a variety of nonpowered boats.

(35) (36) - Response is to yield activities 22.1 (Swimming and Bathing), 22.2 (Diving, skin & scuba), 22.3 (Water Skiing & Other Water Sports).

(37) - Viewing of boating, swimming, and water sports. Yields part of activity 1.3 (Spectator, sports and activities).

(38) - Specify "Viewing team sports & games" to yield part of activity code 1.3 (Spectator, sports and activities).

(39) - Yields activities 62.1 (Nature Study), 71.1 (Acquiring General Knowledge), and 72.1 (Viewing Works of Man).

(40) - Yields activity 64.1 (Gathering Forest Products).

(41) (42) - Yields activities 51.1 (Ice Skating), 51.2 (Sledding, Tobogganing), 51.3 (Skiing), and 51.4 (Snow Play).

(43) (44) - Yields activities 21.1 (Team Sports, track & field), and 21.2 (Games, individual competition).

(45) - Yields activities 61.1 (Hunting, big game), 61.2 (Hunting, small game), 61.3 (Hunting, upland birds), and 61.4 (Hunting, waterfowl).

(46) - Yields activities 81.1 (Viewing Exhibits), 81.2 (Attending Talks and Programs), 81.3 (Tours, guided), 81.4 (Tours, unguided), and 81.5 (General Information).

(47) (48) - All time spent on roads (motorized and nonmotor). Yields parts of activities 11.1 (Auto, driving and motoring), 14.1 (Foot, hiking and walking), 14.2 (Bicycle, bicycling), and 14.3 (Horse, horseback riding).

(49) (50) - All time spent on trails (motorized and nonmotor). Yields parts of activities 11.2 (Scooter and Motorcycle, driving and motoring), 14.1 (Foot, hiking and walking), and 14.3 (Horse, horseback riding).

REGION ______ ①

CORDON SAMPLE

INTERVIEW NUMBER ⑨	TIME ⑩	NUMBER OF PERSONS REPRESENTED ⑪	MONTH ⑫
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FORM 20--RIM CORDON SAMPLE INTERVIEW RECORD

FS-SE-1901-18
BUDGET BUREAU NO 40-6632 —EXPIRES· OCTOBER 31,1966

REGION ______ ① FOREST ______ ② DISTRICT ______ ③ EXIT CLASS ______ ④ EXIT NUMBER ______ ⑤ DATE ______ ⑥

CORDON SAMPLE NO. ______ ⑦ SAMPLING TECHNIQUE NO. 21 ⑧ INTERVIEWER ______

1966 JUNE 1966						
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19	20	21	22	23	24	25
26	27	28	29	30		

1966 JULY 1966						
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1966 AUGUST 1966						
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1966 SEPTEMBER 1966						
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25	26	27	28	29	30	

PERSONS PER CAR RECORD ☒

PERSONS	1	2	3	4	5	6	7	8	9	10
IN STATE										
OUT of STATE										

INTERVIEW NUMBER	TIME	NUMBER OF PERSONS REPRESENTED	ENTERED			TIME IN AREA (SINCE LAST ENTRY)				OVERNIGHT USE (TYPE & LOCATION OF QUARTERS)										DAY USE (ALL TIME NOT SPENT IN OVERNIGHT QUARTERS)																								
			MONTH	DAY	HOUR	TOTAL HOURS	NONRECREATION HOURS (RESIDENT, COMMERCIAL)	RECREATION (TOTAL TIME IN AREA MINUS TIME ON D.S SITES MINUS TIME NONRECREATION EQUALS NET HOURS TO DISTRIBUTE)		TEMPORARY SHELTER (TENT, TRAILER, ETC)				HOTEL, LODGE, RESORT, MOTEL		RECREATION RESIDENCE		ORGANIZATION CAMP		GENERAL ACTIVITY IN VICINITY OF OVERNIGHT QUARTERS	PICNICKING		WATER AND SHORELINE					WATCHING RECREATION ACTIVITIES		NATURE STUDY, NATURAL HISTORY & SCIENCE, WORKS OF MAN, ETC	GATHERING FOREST PRODUCTS	SPORTS & GAMES (LAND)				HUNTING	EXHIBITS, TOURS, AND PROGRAMS	TRAVEL						GENERAL LEISURE AND SIGHT-SEEING
								LIST	HOURS	ON DEV. SITES		ON DISP. AREAS											FISHING	BOATING (INCL. TRAVEL)		SWIMMING & WATER SPORTS						WINTER SPORTS		TEAM SPORTS & PLAY (OTHER)				ROAD		TRAIL		OFF-ROAD OFF-TRAIL		
										NO. OF NIGHTS	AVG HRS PER NIGHT	NO. OF NIGHTS	AVG HRS PER NIGHT	NO OF NIGHTS	AVG HRS PER NIGHT	NO OF NIGHTS	AVG HRS PER NIGHT	NO OF NIGHTS	AVG HRS PER NIGHT		ON DEV SITES	ON DISP AREAS		POWER	NONPOWER	ON DEVELOPED SITES	ON DISPERSED AREAS	ON WATER	ON LAND			ON DEVELOPED SITES	ON DISPERSED AREAS	ON DEVELOPED SITES	ON DISPERSED AREAS			MOTOR	NONMOTOR	MOTOR	NONMOTOR	MOTOR	NONMOTOR	
⑨	⑩	⑪	⑫	⑬	⑭	⑮	⑯	⑰	⑱	⑲	⑳	㉑	㉒	㉓	㉔	㉕	㉖	㉗	㉘	㉙	㉚	㉛	㉜	㉝	㉞	㉟	㊱	㊲	㊳	㊴	㊵	㊶	㊷	㊸	㊹	㊺	㊻	㊼	㊽	㊾	㊿	(51)	(52)	(53)
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INTERVIEW FORM INSTRUCTIONS

①②③ Include data processing code numbers.

④⑤ - Numbers assigned in study plan

⑥ - Date of interviews recorded on this sheet. Do not use for record of more than one day or more than one exit.

⑦ Unique number assigned in W O

⑧ - RIM sampling technique number. Preprinted. No entry required.

⑨ - Preprinted interview number (several per sheet).

⑩ - Record time interview begins in unstippled, upper portion of block. Record time interview ends in stippled, lower portion of block. Use military time.

⑪ - Number of persons represented.

⑫⑬⑭ Use common date and hour (military) for all members of a "household" or "party" interview unit. Record to nearest full hour.

⑮ Number of hours

⑯⑱ - Distribute as recreation and nonrecreation. If all nonrecreation, interview ends.

⑰ - For each interview with recreation time arrive at net hours which exclude recreation time spent on developed sites being simultaneously and separately sampled by double sampling methods.

⑲⑳㉑㉒㉓㉔㉕㉖㉗㉘ Self explanatory. Record number of person nights (number of nights multiplied by number of persons involved) and average number hours per night in each kind of quarters, separately by NF (top line) and other (bottom line). This will yield activity breakdowns of 41.2 (Camping, auto), 41.3 (Camping, trailer), 41.4 (Camping, tent), and the night use component of 46.3 (Recreation Residence).

㉙ - This relates to columns 19-28, inclusive, and is to reflect activity code 41.1 (Camping, general), 41.5 (Organization Camp Camping), 46.1 (Resort and Commercial Public Service), and the day-use component of activity 46.3 (Recreation Residence).

㉚㉛ - On developed sites means any developed site. Dispersed area means any dispersed area element of the recreation population. Response is to yield activity 43.1 (Picnicking).

㉜ - Response is to yield activities 31.1 (Fishing, cold water), 31.2 (Fishing, warm water), 31.3 (Fishing, salt water).

㉝ - Get activities 12.1 and 12.2, which are Boating and Cruising in a variety of powered craft.

㉞ - Get activities 15.1, 15.2, and 15.3, which are Boating in a variety of nonpowered boats.

㉟㊱ Response is to yield activities 22.1 (Swimming and Bathing), 22.2 (Diving, skin & scuba), 22.3 (Water Skiing & Other Water Sports).

㊲ - Viewing of boating, swimming, and water sports. Yields part of activity 1.3 (Spectator, sports and activities).

㊳ - Specify "Viewing team sports & games" to yield part of activity code 1.3 (Spectator, sports and activities).

㊴ - Yields activities 62.1 (Nature Study), 71.1 (Acquiring General Knowledge), and 72.1 (Viewing Works of Man).

㊵ - Yields activity 64.1 (Gathering Forest Products).

㊶㊷ - Yields activities 51.1 (Ice Skating), 51.2 (Sledding, Tobogganing), 51.3 (Skiing), and 51.4 (Snow Play).

㊸㊹ - Yields activities 21.1 (Team Sports, track & field), and 21.2 (Games, individual competition)

㊺ Yields activities 61.1 (Hunting, big game), 61.2 (Hunting, small game), 61.3 (Hunting, upland birds), and 61.4 (Hunting, waterfowl)

㊻ Yields activities 81.1 (Viewing Exhibits), 81.2 (Attending Talks and Programs), 81.3 (Tours, guided), 81.4 (Tours, unguided), and 81.5 (General Information).

㊼㊽ - All time spent on roads (motorized and nonmotor). Yields parts of activities 11.1 (Auto, driving and motoring), 14.1 (Foot, hiking and walking), 14.2 (Bicycle, bicycling), and 14.3 (Horse, horseback riding).

㊾㊿ All time spent on trails (motorized and nonmotor). Yields parts of activities 11.2 (Scooter and Motorcycle, driving and motoring), 14.1 (Foot, hiking and walking), and 14.3 (Horse, horseback riding).

(51)(52) All time spent in off-road and off trail travel. Yields parts of activities 11.1 (Auto, driving and motoring), 11.2 (Scooter and Motorcycle, driving and motoring), 11.3 (Ice and Snowcraft, driving and motoring), 14.1 (Foot, hiking and walking), 14.2 (Bicycle, bicycling), 14.3 (Horse, horseback riding), and all of activity 63.1 (Mountain Climbing).

(53) - Yields activities 1.1 (Viewing Outstanding Scenery) and 1.2 (Enjoying a Unique or Unusual Environment).

U. S. Forest Service Research Paper SE- 32 April 1968

Soil or Foliar Fertilization of Well-Drained and Flooded Slash Pine Seedlings

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U.S. Department of Agriculture - Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

Soil or Foliar Fertilization of Well-Drained and Flooded Slash Pine Seedlings[1]

by

Robert P. Schultz, Plant Physiologist
Naval Stores and Timber Production Laboratory
Olustee, Florida

The establishment and growth of slash pine (Pinus elliottii Engelm. var. elliottii) is seriously handicapped on many Southeastern Coastal Plain sites. Such sites are characterized by Groundwater Podzol and Humic Gley soils that are low in total and available nutrients, poorly drained, and subject to occasional flooding. Because of an increase in the demand for wood products, these submarginal sites are being planted to slash pine. To increase productivity of these areas, problems related to water control, site preparation, and tree nutrition should be solved.

Although southern pines do not always respond to fertilizers, research has demonstrated that supplemental nutrients on low fertility soils can significantly increase pine production (Walker and Tisdale 1959; Walker 1965). Consistent growth increases have been obtained in slash pine on wet flatwoods sites through soil fertilization with phosphorus or phosphorus plus nitrogen (Pritchett and Swinford 1961; Curtis 1964; Pritchett 1964; Pritchett and Llewellyn 1966).

Slash pine and loblolly pine (Pinus taeda L.) seedlings can survive for long periods of time under poorly drained or flooded conditions provided the tops of the seedlings remain above water (Walker et al. 1961; Ralston 1965). Lowering the water table by digging networks of drainage ditches and by bedding (creating ridges with a plow) greatly improved the growth of newly established seedlings on wet areas. Fertilizing flooded seedlings of slash and loblolly pine greatly reduced both their survival and their growth (Walker 1962). Draining the soils to a depth of 4 inches below the surface and then fertilizing the seedlings resulted in appreciable growth responses and increased foliar concentrations of nitrogen, phosphorus, and potassium. Response of slash pine to P and N fertilizers on a bedded "grass flat" near Carrabelle, Florida, suggested that fertilization might enhance the effectiveness of bedding (Pritchett and Llewellyn 1963).

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[1] The study was designed and initiated by G. W. Bengtson, formerly employed by this Station.

This paper reports on the development of slash pine seedlings placed in pots in a lathhouse under conditions of controlled fertilization and moisture regime. The objectives were to evaluate the effects of flooded vs. well-drained soil and foliar vs. soil fertilization on the growth and nutrient accumulation of young slash pine.

EXPERIMENTAL METHODS

A total of 540 one-year-old slash pine seedlings were lifted in January 1965 from the Florida Forest Service Nursery, Baker County, Florida. Sixty of the seedlings were randomly selected as pretreatment controls. They were ovendried at 70° C. and the shoot and root dry weights determined separately. Composite groups (roots + shoots) were ground in a Wiley mill, passed through a 20-mesh sieve, mixed thoroughly, and subsampled for chemical analyses.

The remaining 480 seedlings were planted in individual 6-inch plastic pots. The potting medium was a Bladen fine sandy loam which is an acid flatwoods soil low in P and N. The seedlings were randomly assigned to one of four equal groups for fertilizer treatments, as follows: (1) control--no fertilizer; (2) foliar fertilization--foliage dip in 0.50 $\underline{M}$ solution of diammonium phosphate prior to planting; (3) soil fertilization--equivalent of 100 lb. each of N and P applied to the soil surface as a water solution of diammonium phosphate; and (4) foliage dip plus soil fertilization, as above.

The 120 seedlings of each fertilizer treatment were randomly separated into two groups of 60; one group was assigned to the flooding treatment, and the other to the well-drained treatment. These groups were then divided into four lots of 15 seedlings each for assignment among four concrete tanks. Each tank was divided in half by a wooden frame. Polyethylene was placed in one side of each tank in the form of a basin to maintain the water level at the soil surface of the pots. In the other side of each tank, the pots were placed on planks to assure good drainage. Water used in this study was pumped from a nearby flatwoods pond in order to approximate the type of ground water to which slash pine seedlings on flatwoods sites are subjected.

In late October 1965 the height growth (1965 growing season) of each surviving seedling was measured. The seedlings were then lifted and their roots washed free of soil; each seedling was ovendried at 70° C. and weighed. All seedling materials from each 15-tree treatment group were combined, ground in a mill, and subsampled in the same manner as the pretreatment control seedlings had been.

Total N was determined by Kjeldahl analysis of 1-gram tissue samples. After dry ashing 2-gram tissue samples, P was determined by the molybdate vanadate colorimetric method, and K by means of a Beckman DU flame spectrophotometer. The product of the percent of N, P, and K times the total dry weight of the seedlings in each treatment group was used to estimate the total nutrient content of the seedlings before and after treatment and the net nutrient uptake among treatments.

Height growth, shoot and root dry-weight increments, shoot-to-root ratios, and nutrient (N, P, K) uptake as affected by treatments were subjected to analysis of variance.

RESULTS AND DISCUSSION

MORTALITY

Sixteen percent of the well-drained seedlings died, as compared with 25 percent of the flooded seedlings (table 1). This difference is significant at the 5-percent level (table 2). All mortality occurred within 4 months after planting.

Table 1.--Effects of 9 months of moisture control and fertilization on growth and mineral absorption of slash pine seedlings

Seedling treatment	Mortality	Height increments[1]	Plant dry-weight increments[1]			Mineral absorption[1]		
			Shoot	Root	S/R ratio	N	P	K
	Percent	Centimeters	- Grams -			- Milligrams -		
Drained								
Control	16.7	14.72	5.35	2.93	1.83	18.52	1.39	0.31
Foliar fertilization	24.0	14.00	5.48	3.00	1.83	17.82	3.03	0.43
Soil fertilization	13.3	18.57	11.91	6.63	1.80	58.07	16.97	6.78
Foliar + soil fertilization	15.0	18.42	13.92	7.15	1.95	64.02	19.99	9.07
Average	16.2	16.43	9.16	4.93	1.85	39.61	10.35	4.15
Flooded								
Control	30.0	13.52	4.20	1.99	2.11	2.50	-1.09	-2.96
Foliar fertilization	10.0	13.72	4.44	1.95	2.28	3.15	0.27	0.72
Soil fertilization	26.7	12.95	6.10	2.45	2.49	13.87	4.09	-3.63
Foliar + soil fertilization	31.7	13.75	6.59	2.66	2.48	17.72	5.34	-1.13
Average	24.6	13.48	5.33	2.26	2.34	9.31	2.15	-1.75

[1] Based on an average of from 41 to 54 seedlings.

Fertilization had no significant influence on mortality. Seedlings that received foliar fertilization showed a much higher mortality under well-drained conditions than under flooding primarily because of a high mortality rate in a single well-drained plot.

GROWTH

More rapid growth and better vigor of the well-drained seedlings were evident within 3 months after planting. Within the well-drained treatments, seedlings that received N + P by soil application or N + P by foliar and soil application had darker green foliage and were growing more rapidly than either the untreated controls or the foliar-fertilized seedlings. Within the flooded group, no effects of fertilizer treatment were visible. Many seedlings had started good height growth despite the flooding, but their needles were somewhat chlorotic.

Table 2.--Analysis of variance of mortality and growth, expressed in F values

Source of variation	d.f.	Mortality	Height increment	Plant dry-weight increments		
				Shoot	Root	Shoot/Root ratio
Block (K)	3	4.95	1.02	0.77	1.17	0.56
Flooding (W)	1	16.67*	13.46*	47.35**	247.13**	12.25*
Error A (KxW)	3					
Fertilizer treatment (F)	3	1.29	4.82*	51.24**	52.92**	10.00**
c vs. f+s+(f+s)[1]	1	0.94	3.52	53.45**	52.88**	20.00**
f vs. s+(f+s)	1	2.46	10.75**	95.16**	103.85**	8.00*
s vs. (f+s)	1	0.46	0.20	5.13*	2.08	1.00
Fertilizer x Flooding (FxW)	3	3.15	6.43**	16.98**	28.81**	7.00**
Wx[c vs. f+s+(f+s)]	1	0.69	3.84	15.69**	30.73**	14.00**
Wx[f vs. s+(f+s)]	1	8.64**	15.02**	33.38**	55.35**	4.00
Wx[s vs. (f+s)]	1	0.12	0.43	1.88	0.35	3.00
Error B[(KxF)+(KxWxF)]	18					
Total	31					

[1] c - control
f - foliar fertilization
s - soil fertilization
(f+s) - foliar + soil fertilization

*Significant at 5-percent level
**Significant at 1-percent level

At time of lifting, seedlings growing in well-drained soil were obviously superior in height, diameter, foliar color, needle length, and density to those growing in flooded soil. The flooded seedlings had buttressed bases. Continuous soil saturation probably produced a girdle at the root collar which reduced downward translocation and caused swelling.

Most flooded seedlings had only a few lateral roots. The succulent root tips were short and blunt--an indication of very slow growth. The seedlings also had few second- and third-order roots. Most third- and fourth-order roots were only visible as knobby protrusions. In contrast, the well-drained seedlings had relatively long, succulent growing tips and numerous second-, third-, and fourth-order roots. The well-drained seedlings often had masses of mycorrhizae while those which were flooded had only a few or no mycorrhizal roots. Other workers have noted this phenomenon in both slash and loblolly pine (Pessin 1928; Zak 1961). The occurrence of mycorrhizal roots on flooded seedlings was almost exclusively confined to the upper 1/4 inch of the soil surface. Apparently aeration was inadequate at greater depths.

Soil fertilization and foliar plus soil fertilization with N + P greatly increased growth under well-drained conditions but had considerably less effect under flooded conditions (tables 1 and 2). The combined foliar plus soil fertilization treatment was not significantly better than soil fertilization, except for shoot dry weight. Similarly, foliar fertilization was not significantly better than the untreated control.

Flooding significantly reduced growth of trees, regardless of fertilizer treatment. Shoot-to-root ratios were increased because flooding reduced root growth more than shoot growth. The average root dry weight of flooded seedlings (2.26 g.) was less than one-half that of the well-drained seedlings (4.93 g.). The dry-weight increments of the shoots of well-drained seedlings were 72 percent greater than those of flooded seedlings.

Under well-drained conditions, soil fertilization increased seedling dry weight 124 percent and height growth 26 percent over untreated controls. Foliar plus soil fertilization increased the same measurements 154 and 25 percent, respectively. Under flooded conditions, soil fertilization increased seedling dry weight 38 percent over that of nonfertilized seedlings, and foliar plus soil fertilization increased the dry weight 49 percent; neither treatment affected height growth. The fact that N + P when applied to the soil or to the soil plus foliage of well-drained seedlings more than doubled their dry-weight increment over one growing season tends to overshadow the fact that these same treatments greatly increased dry-weight increment of flooded seedlings also. It is quite possible that the 23 to 34 percent increase in root systems obtained from fertilizing flooded seedlings could make the difference between survival or death, especially if the soil rapidly dried to the wilting point as sometimes occurs in the flatwoods. Also, this increased root growth could pave the way for much greater growth increases as soon as conditions become more favorable.

MINERAL ABSORPTION

Mineral absorption was only one-fourth as great under flooded as under well-drained conditions (tables 1 and 3). The limited new root and mycorrhizal development greatly reduced the absorbing surfaces of flooded seedlings. This reduction, combined with poor soil aeration, probably had a limiting effect on both water and mineral absorption. Also, the total amount of N and P absorption was reduced under flooded conditions because N is readily leached in flooded soils, and more P was probably tied up in unavailable forms. The fact that seedlings growing in flooded soil did not absorb any K is not surprising--flooding augments leaching of K ions so that they are generally taken up in smaller quantities under waterlogged conditions.

Under both moisture conditions, foliar fertilization resulted in a nonsignificant increase in nutrient uptake over that of the untreated controls. Because foliar fertilization did not significantly increase either the nutrient uptake or the growth of the seedlings, it appears that the plants did not absorb significant amounts of nutrients through the needles. In contrast, Schopmeyer (1961) noted that loblolly pine seedlings, grown in phosphorus-deficient culture solutions, rapidly absorbed large amounts of P when it was applied to the needles, and that height growth was more than double that of seedlings receiving no P.

Table 3.--Analyses of variance of mineral absorption, expressed in F values

Source of variation	d.f.	Nitrogen	Phosphorus	Potassium
Block (K)	3	0.42	2.46	1.87
Flooding (W)	1	161.85**	437.13**	17.98*
Error A (KxW)	3			
Fertilizer treatment (F)	3	79.74**	104.40**	3.24*
c vs. f+s+(f+s)[1]	1	78.39**	131.82**	5.66*
f vs. s+(f+s)	1	157.20**	175.35**	2.14
s vs. (f+s)	1	3.63	6.04*	1.91
Fertilizer x Flooding (FxW)	3	22.59**	27.85**	4.67*
Wx[c vs. f+s+(f+s)]	1	20.52**	28.87**	1.53
Wx[f vs. s+(f+s)]	1	47.07**	53.63**	12.47**
Wx[s vs. (f+s)]	1	0.17	1.04	0.00
Error B[(KxF)+(KxWxF)]	18			
Total	31			

[1] c - control
f - foliar fertilization
s - soil fertilization
(f+s) - foliar + soil fertilization

*Significant at 5-percent level
**Significant at 1-percent level

Soil fertilization or foliar plus soil fertilization resulted in significantly higher mineral absorption under both flooded and well-drained conditions than did no fertilization (tables 1 and 3). Seedlings receiving a foliar plus soil application of N + P did not absorb significantly more nutrients than did seedlings receiving a soil application only. Under well-drained conditions, soil fertilization and foliar plus soil fertilization resulted in 2 to 14 times more N and P absorption than did no fertilization. Under well-drained conditions, K, although not included in any of the fertilization treatments, was increased in the tissue 22-fold by soil fertilization and 29-fold by foliar plus soil fertilization. This may have been the result of more extensive and vigorous root systems and increased availability of K with the addition of N + P fertilizers. Under flooded conditions, soil fertilization or foliar plus soil fertilization increased N and P five to seven times over foliar-fertilized or unfertilized seedlings but had little effect on K.

CONCLUSIONS

Flooding is an important factor controlling both survival and growth of slash pine planted under flatwoods conditions. Survival the first year after outplanting was significantly better on well-drained soil than on soil which was continuously saturated. Seedling response was much greater when the fertilization was accompanied by drainage. Flooding not only reduced the capacity of the roots to absorb water and nutrients but was probably the major factor in reducing new root formation and mycorrhizal development. This in turn decreased the absorbing surface, further decreased the rate of mineral uptake, and subsequently reduced seedling growth and vigor.

Because foliar fertilization had no added growth effect over no fertilization, either under flooded or well-drained conditions, it appeared that slash pine seedlings do not absorb significant amounts of nutrients through the needles.

On well-drained, nutrient-deficient soils the early growth of seedlings which received soil fertilization was twice that of unfertilized stock. In addition, soil-fertilized seedlings accumulated a greater amount of nutrients. Soil fertilization was much less effective under flooded conditions, but the increased growth and mineral absorption was probably sufficient to give seedlings an advantage for survival and growth during subsequent years. Although the combination of foliar plus soil fertilization increased growth and mineral absorption under both flooded and well-drained conditions, it was not appreciably better than soil fertilization alone.

These results suggest that a single foliar application of N and P prior to planting will not improve the growth of slash pine seedlings. However, soil fertilization in areas deficient in N and P will probably yield worthwhile growth increases of young slash pine on both wet and well-drained flatwoods soils.

LITERATURE CITED

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U. S. Forest Service Research Paper SE-33 April 1968

Seasonal and Diurnal Variation in Moisture Content of Six Species of Pocosin Shrubs

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ACKNOWLEDGMENT

This report is based on results obtained through a cooperative study by the Southeastern Forest Experiment Station, Southern Forest Fire Laboratory, and the North Carolina Department of Conservation and Development, Division of Forestry. Region 1 of the North Carolina Division of Forestry provided personnel and laboratory space required for collecting and making preliminary summaries of all field data. The Southern Forest Fire Laboratory provided technical support and necessary supplies and equipment.

Cover photo: A gallberry plant is collected from the dense mixture of finely branched deciduous and evergreen shrubs growing on an organic, pocosin soil in eastern North Carolina. A fuel complex like this can become highly flammable in the dormant season when the dead fuels become dry and the living fuels are at a low point in their annual cycle of moisture content. This photograph was taken in April 1965, a few weeks prior to the rapid spring buildup in the moisture content of live fuel.

Southeastern Forest Experiment Station - Asheville - North Carolina
U.S. Department of Agriculture - Forest Service

Seasonal and Diurnal Variation in Moisture Content of Six Species of Pocosin Shrubs

by

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and

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North Carolina Division of Forestry

INTRODUCTION

Understory shrubs growing on organic soils in pocosins of the eastern North Carolina coastal plain can become a particularly severe fire hazard during certain dry seasons of the year. These shrubs commonly form dense thickets of highly flammable fuels capable of supporting very intense wildfires. Such fires, once started, often have the potential for widespread destruction because of control difficulties in these relatively unbroken and inaccessible expanses of vegetation.

The peculiar branching habit of these shrubs probably contributes to their high flammability. Their foliage and stems usually form a dense, relatively homogeneous mixture of finely divided fuel particles suspended just above the litter. In addition, the leaves of many species of pocosin shrubs remain on the plant through the winter. Thus, they increase the proportion of easily ignited fine fuel particles distributed throughout the fuel complex during the dormant season.

Practical experience in fire control in the organic soils area has suggested that moisture content of these shrubs may be one of the more important factors influencing fire behavior. The most intense and difficult-to-control fires tend to occur during the spring and fall, two seasons of the year in which moisture content of the shrub undergrowth is relatively low. Other environmental factors, such as precipitation, wind, and relative humidity, are often at a level favoring high flammability at these seasons.

Wendel and Storey[1] showed that a definite pattern of seasonal moisture variation exists for several species of vegetation found on pocosin soils on the Hofmann Forest in eastern North Carolina. In 1959 they observed moisture fluctuations over a 1-year period in four common species: gallberry (*Ilex glabra* (L.) Gray), swamp cyrilla (*Cyrilla racemiflora* L.), redbay (*Persea borbonia* (L.) Spreng.), and switch cane (*Arundinaria tecta* (Walt.) Muhl.). The general pattern of moisture variation during this time was similar for the four species. All showed a rather rapid increase in moisture content during the period of growth resumption in the spring, followed by a gradual decline in moisture through the summer on into fall and winter. However, moisture content at any given time during the year was apt to vary widely among the four species.

Although Wendel and Storey's data provided valuable insight into general patterns of seasonal moisture variation in pocosin shrubs, additional information was needed to establish trends for other years and to describe other, more specific characteristics of the moisture regime in these fuels. This report explores four questions concerning the moisture regime in pocosin shrubs, namely: (1) How does the pattern of seasonal moisture variation during other annual growth cycles compare with Wendel and Storey's data for 1959? (2) How does moisture content differ among stems, new leaves, and old leaves? (3) How is the timing of new growth initiation in the spring related to the buildup in moisture content of the whole plant? and (4) Does diurnal variation in moisture content occur in pocosin shrubs?

METHODS

Seasonal variation in moisture content was observed in six species of pocosin shrubs over a 10-month period from March through December 1965. The six species included the four that Wendel studied (gallberry, swamp cyrilla, redbay, and switch cane) plus two others, fetterbush (*Lyonia lucida* (Lam.) K. Koch) and honeycup (*Zenobia pulverulenta* (Bartr.) Pollard). (Although switch cane is not technically a shrub, for simplicity it will be so termed throughout this paper.)

Samples were collected on six plots located on the Hofmann Forest in eastern North Carolina. Each species was sampled on a different plot. Transects had been laid out on each plot as shown in figure 1. Samples were collected on these transects once each week between noon and 4 p.m. On a given plot, samples were obtained by clipping a suitable plant near each of the five subsample points along a transect; separating each whole plant into stems, current year's foliage, and previous year's foliage; and combining subsamples of each type of tissue into one composite sample for each of the three transects on a plot. Moisture content of the samples was determined by ovendrying for 24 hours at 103° C.

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[1] Wendel, George W., and Storey, Theodore G. Seasonal moisture fluctuations in four species of pocosin vegetation. U. S. Forest Serv. Southeast. Forest Exp. Sta. Pap. 147, 9 pp., illus. 1962.

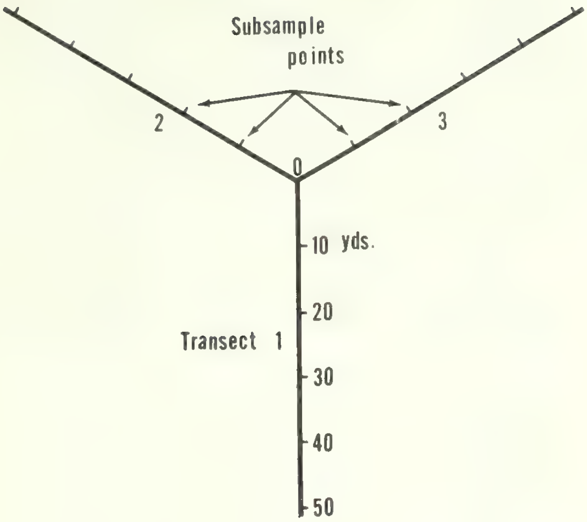

Figure 1.--Layout of transects on each plot from which samples were obtained. (Subsamples were collected at the indicated points along each transect, then combined to make three composite samples, one from each of the three transects on a plot.)

Diurnal variation in moisture content of the current year's foliage was observed in four species: gallberry, swamp cyrilla, honeycup, and fetterbush. Samples were collected every 4 hours throughout a 36-hour period on June 21 and 22, 1965. Samples of a given species were taken from a single clump composed of numerous plants. We collected each sample by clipping four to six terminal shoots to provide approximately 10 grams of fresh leaf tissue, taking all foliage samples from the lower two-thirds of the shoot,[2] blotting with a paper towel to remove surface moisture if present, and combining leaf tissue from each of the terminal shoots into one composite sample. Five composite samples of each species were collected every 4 hours. Moisture content was determined by ovendrying for 18 hours at 103° C.

RESULTS AND DISCUSSION

Seasonal Variation

The patterns of seasonal variation in moisture content of leaves and stems were, in general, similar for nearly all species. However, noticeable differences did occur (figures 2a-2f).

Moisture content of new leaves was very high (200 to 400 percent) when the leaves first appeared in the spring. It declined rapidly during the first 4 to 6 weeks after initiation and then decreased gradually through the rest of the summer on into the winter months. Leaves that had remained on the three evergreen species (gallberry, fetterbush, and redbay) from the 1964 growing season through the winter of 1965 had about the same moisture content in March 1965 that the current year's leaves had attained by December 1965. This relationship suggests that little change in the moisture content of leaves takes place through the winter months, a characteristic which Wendel also noted. The curves for moisture content of previous year's foliage show a slight increase about the time of new foliage initiation.

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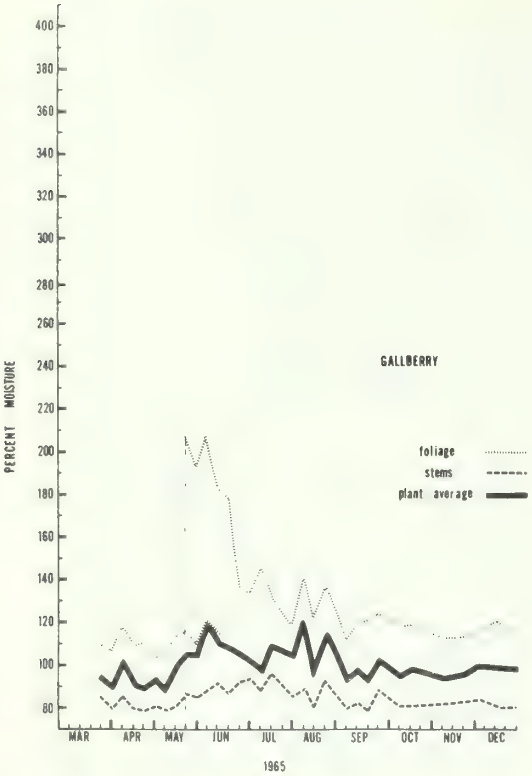
[2] To reduce experimental error resulting from variation in stage of maturity of terminal leaves, only the leaves from the lower two-thirds of the stem were used.


GALLBERRY
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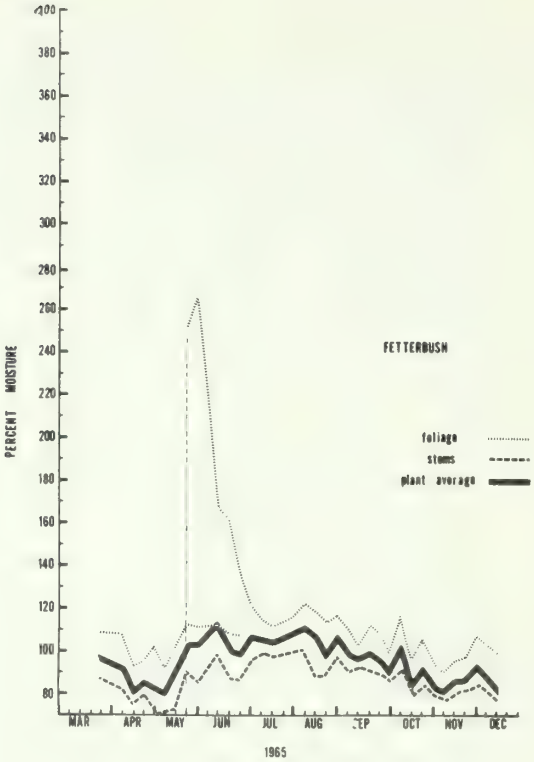
a


FETTERBUSH
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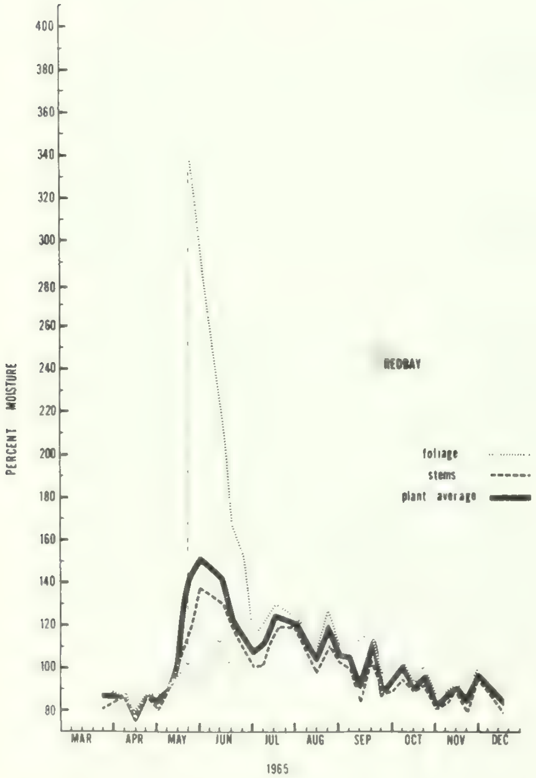
REDBAY
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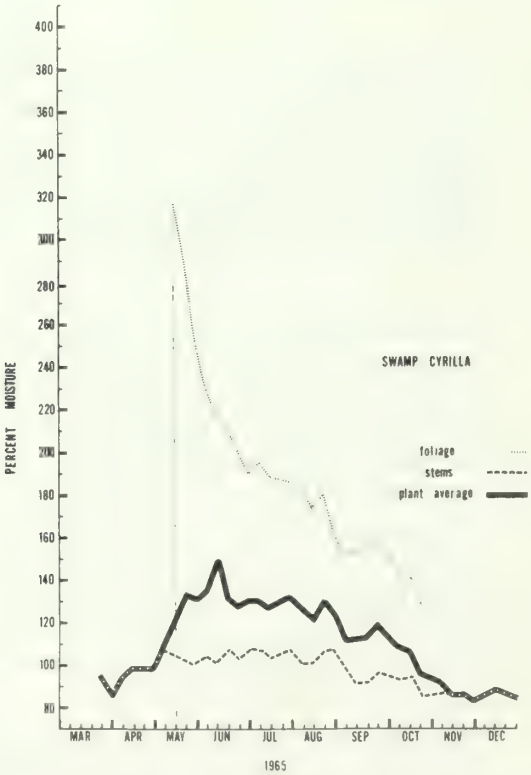
SWAMP CYRILLA
PERCENT MOISTURE
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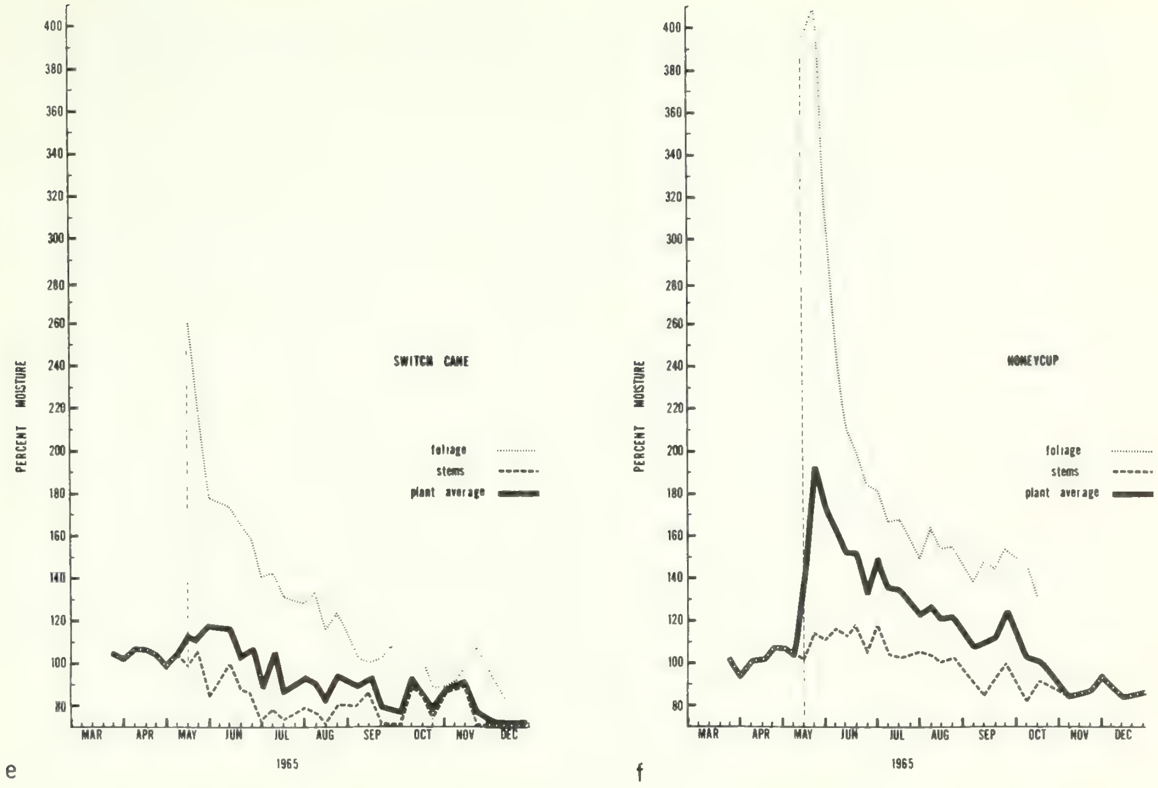

Figure 2.--Annual cycle of variation in moisture content of six pocosin shrub species during 1965. The moisture content of previous year's foliage in a, b, and c is plotted separately from that of new foliage initiated during the 1965 growing season. (Percent of moisture based on ovendry weight of sample.)

Apparently, the leaves of the three evergreen species persist on the plant for only 1 year. During this particular year (1965), previous year's leaves dropped off from 4 to 6 weeks after new foliage initiation.

The moisture content of the stems of most species was lowest during April and the early part of May and during the period from September through December. It increased noticeably during the latter part of May and all of June, then gradually declined through the summer, fall, and winter. Switch cane was an exception in that it exhibited no spring increase in stem moisture. Instead, the moisture content of its stems declined steadily throughout the spring and summer. The spring increase in the moisture content of swamp cyrilla stems began during April, about a month earlier than in the other species.

The curves for the moisture content of stems represent an average of moisture in both new and old stem tissue. If the moisture content of newly formed stem tissue follows a pattern similar to that of newly formed leaves, the spring increase in average moisture content of new and old stems may be largely due to increased concentrations of water in the rapidly expanding new shoots and newly formed cambium tissue. If this is true, then most of the water in the whole plant is concentrated in the smaller fuel particles (leaves and small stems) and in a layer covering the outer surface of all living stems. This rather uneven distribution of moisture within the fuel complex might be an important consideration in evaluating the influence of the moisture content of live fuel on fire behavior.

The difference between the moisture content of leaves and that of stems was not consistent throughout the year. Although leaves, in general, maintained a higher moisture content at all times than did stems, the greatest difference occurred in the spring just after new leaves appeared on the plant. At this time, leaves were from 100 to 200 percent higher in moisture content than were stems. This wide difference lasted for only a few weeks because of the rapid decline in moisture content usually associated with continued development of new tissue. The difference between the moisture content of leaves and stems for the three deciduous species (swamp cyrilla, honeycup, and switch cane) gradually decreased as the leaves continued to develop through the summer until they dropped off in the fall. On the other hand, in the three evergreen species the difference had stabilized by midsummer, about the time the previous year's leaves dropped off. Thereafter, the difference remained about the same (10 to 30 percent) throughout the fall and winter months. The curve of moisture content for previous year's leaves suggests that this 10- to 30-percent difference may continue through the winter until the following summer when the older leaves drop off. Redbay was an exception in that the moisture content of its stems increased above the moisture content of the previous year's leaves just prior to new foliage initiation.

The difference between the moisture content of leaves and stems also varied considerably among species. For example, in redbay the moisture content of leaves ranged within 15 percent of the moisture content of stems over the entire period except during the 6 weeks following new foliage initiation. On the other hand, in honeycup and swamp cyrilla the moisture content leaves ranged well over 40 percent higher than that of stems most of the time. Wendel and Storey (see footnote 1) found similar patterns in swamp cyrilla and redbay during 1959.

The average moisture content of the whole plant was generally lowest during the dormant season (November-April). A marked increase occurred in May with the onset of new growth, gradually tapering off through the summer. In all species except switch cane, this spring increase was a result of increases in the moisture content of both foliage and stems. The moisture content of switch cane stems showed no increase in the spring but continued to decline through spring and summer.

In addition to the broad seasonal trends of variation in moisture content, figures 2a-2f show week-to-week fluctuations in the moisture content of some species which are too large to be explained solely by random variation among repeated samples. The week-to-week fluctuations often greatly exceeded 95-percent confidence limits on the means used to plot curves in figures 2a-2f. (These confidence limits ranged from

$\bar{x} \pm 6\%$ to $\bar{x} \pm 11\%$.[3]) Uneven rates of growth or irregularly occurring diurnal fluctuations in moisture content caused by changing weather conditions may have caused these short-term fluctuations.

The relative proportions of foliage and stem tissue of the evergreen species fluctuated throughout the year. The proportion of foliage tissue was lowest during April and May and during September and October. During these periods the proportion of foliage decreased to around one-third of the total dry weight of the plant. The proportion of foliage increased to as high as one-half in August but was, with a few exceptions, never more than this.

The rapid increase in moisture content of the whole plant in the spring seems to be correlated with new foliage initiation. This increase in moisture content began about 1 to 2 weeks before collection of the first new foliage samples (figures 2a-2f). As bud break had also occurred about 1 to 2 weeks prior to this collection, it appears that bud break and the beginning of the rapid increase in moisture content of the whole plant occurred in each species at about the same time. The moisture content of the whole plant seemed to reach a maximum about 1 to 2 weeks after the first samples of new foliage were collected. It is noteworthy that the first samples of new foliage were collected for all six species at about the middle of the period of rapid increase in the moisture content of the whole plant. If this relationship is typical of most years, observations of the time of bud break and initiation of rapid leaf expansion in the spring might be useful in detecting the onset of the rapid spring increase in moisture content of these pocosin fuels.

The time of bud break and initiation of new foliage differed among the six species. The separation of one week between dates of the first samples of new foliage shown in figures 2a-2f reflects this difference. Numerous observations made while collecting samples also showed, however, that the date of bud break and initiation of new foliage differed among individual plants of the same species growing on different sites.

These data and Wendel and Storey's earlier study confirm the existence of marked seasonal fluctuation in moisture content of pocosin shrubs. Minima occur at a time of year when fire occurrence and difficulty of control are usually highest in the pocosin area, the spring and fall months. However, the important question of just how influential the moisture content factor is in affecting fire behavior remains unanswered. Further study of the relationship between actual flammability and moisture content of pocosin plants in various stages of the annual growth cycle is needed to make these and other studies of variation in moisture content more useful in predicting fire behavior.

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[3] These confidence limits do not apply to that portion of the new foliage curves exhibiting the rapid decrease in moisture content during the first 4 to 6 weeks of development.

Diurnal Variation

Previous research has already shown that local environmental conditions characterized by clear, hot days or inadequate soil moisture can cause reduced moisture content in the leaves of some plants during the afternoon hours. On the other hand, on cool, cloudy, or rainy days when there is adequate soil moisture, little or no reduction may take place.[4]

We took samples of foliage from four species (gallberry, swamp cyrilla, honeycup, and fetterbush) over a 36-hour period during June 1965 to see if we could detect a diurnal fluctuation in moisture content. We purposely chose to sample current year's foliage tissue at a time just after the leaves were fully expanded but while moisture content was still relatively high (150 to 200 percent). If diurnal variation did occur at all, we reasoned that it would be more pronounced in foliage tissue at this time of year. We chose a sampling period when the days were relatively hot and clear and the soil was well supplied with moisture. Figure 3 reflects diurnal air temperature, relative humidity, and solar radiation cycles for the period.

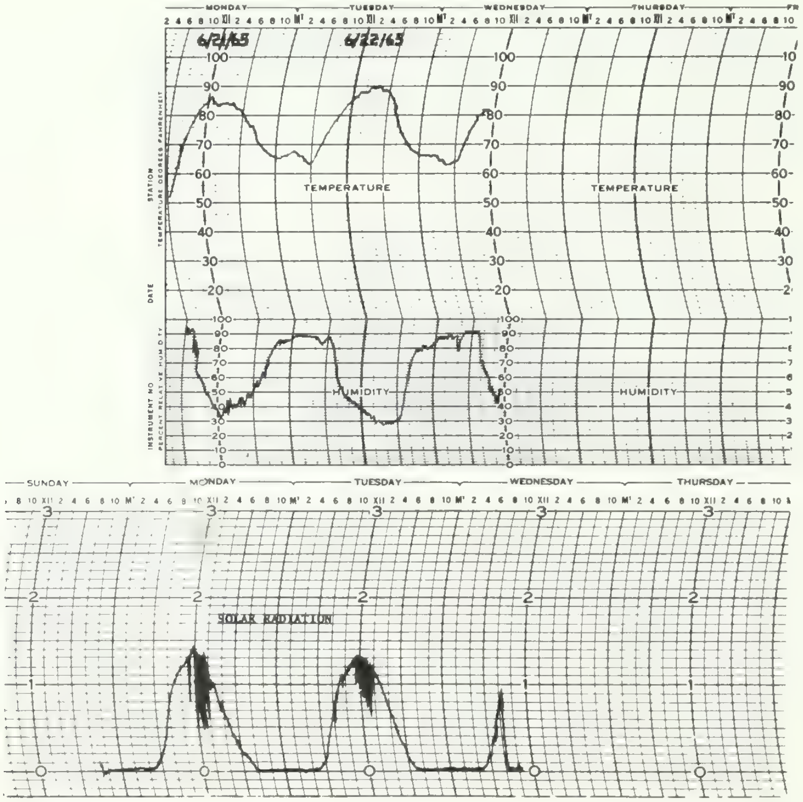

Figure 3.--Variation in air temperature, relative humidity, and solar radiation intensity during the 36-hour period when diurnal variation in moisture content of foliage was measured.

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[4] Meyer, B. S., Anderson, D. B., and Bohning, R. H. Introduction to plant physiology. 541 pp., illus. New Jersey: D. Van Nostrand Company, Inc. 1960.

Our results indicate that diurnal fluctuation in moisture content can occur in the four species studied, at least under the weather conditions prevailing at the time of this study. According to figure 4, maximum moisture contents occurred between 2 and 6 a.m. Minima occurred about 2 p.m. During the 36-hour sample period, gallberry fluctuated from about 143 to 180 percent; cyrilla from about 152 to 178 percent; honeycup from about 162 to 205 percent; and fetterbush from about 165 to 204 percent.

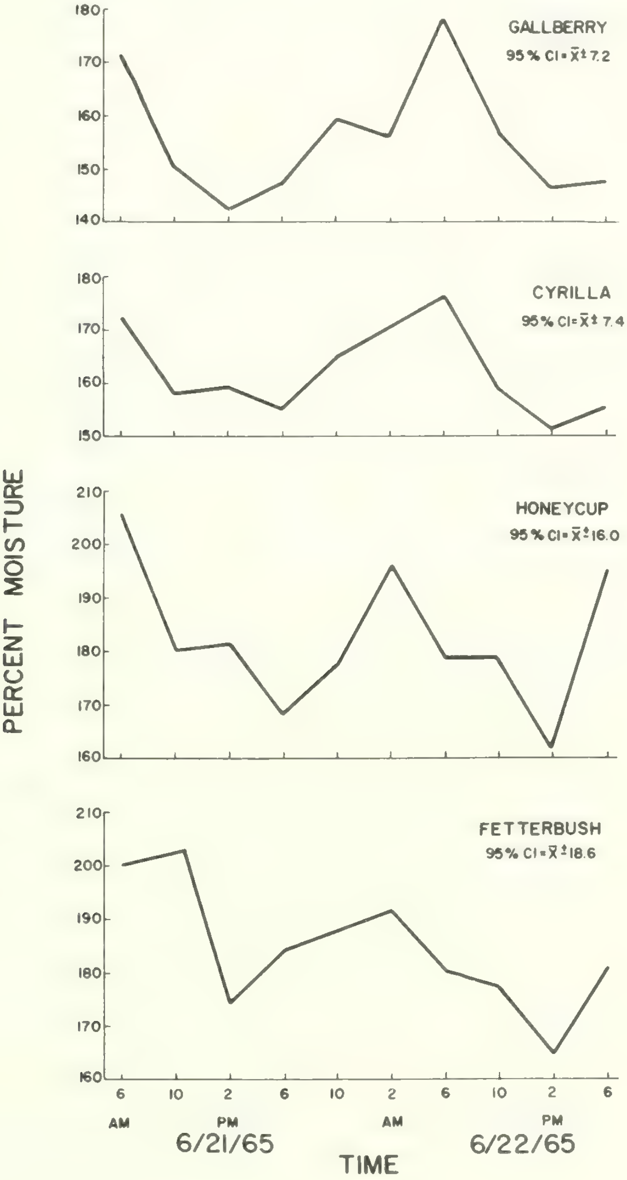

Figure 4.--Diurnal variation in foliage moisture content of four pocosin shrub species. (Percent moisture based on ovendry weight of sample.)

If this much diurnal fluctuation can occur in foliage tissue at this stage of maturity, then it seems that measurable but perhaps smaller fluctuations might also occur at other times of the year. Buck,[5] reporting from California, detected some diurnal variation in manzanita (Arctostaphylos spp.) and snowbrush (Ceanothus velutinus) at various times throughout the entire growing season. Further study of diurnal changes in moisture content of stems as well as foliage at other times of the year could help establish the frequency and degree of occurrence of this phenomenon in pocosin fuels. Such studies should explore the relationship of important environmental conditions such as air temperature, solar radiation, and soil moisture to diurnal moisture cycles. Further, they should attempt to establish the significance of this phenomenon to fire behavior.

SUMMARY

Seasonal variation in moisture content of six pocosin shrub species (gallberry, swamp cyrilla, redbay, switch cane, fetterbush, and honeycup) found on the Hofmann Forest in eastern North Carolina was observed over a 10-month period from March through December 1965. The moisture content of foliage and that of stems was measured separately and compared with the average moisture content for the whole plant.

Diurnal variation in moisture content was observed in foliage tissue of four pocosin shrub species (gallberry, swamp cyrilla, honeycup, and fetterbush) over a 36-hour period during June 21 and 22, 1965.

Minimum moisture contents occurred in the spring and fall in most species. A marked increase in moisture content occurred during May and June with the highest moisture content for the whole plant occurring some time during the first 2 weeks of June.

At any given time of year, leaves almost always had a higher moisture content than stems, but the difference between leaf and stem moisture varied considerably among species and according to the time of year. The difference between the moisture content of leaves and stems tended to be greater in the deciduous species than in the evergreen species.

Leaves on the evergreen species remained on the plant for 13 to 14 months or about 4 to 6 weeks beyond the time that new foliage was initiated the following spring.

The degree of influence that leaves or stems had on the average moisture content of the whole plant varied considerably according to the time of year and stage of plant development within the annual growth cycle. In some species the marked increase in the average moisture

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[5] Buck, Charles C. Progress report on variations in the moisture content of green brush foliage on the Shasta Experimental Forest during 1937. Calif. Forest and Range Exp. Sta., 10 pp. 1939. (Unpub. misc. rep.)

content of the whole plant in the spring was mainly a reflection of the rapid initial development of new foliage. However, because leaf tissue constituted a small proportion of the whole plant (based on dry weight), the average moisture content of the whole plant was usually nearer the level of the moisture content of stems than that of leaves. During late summer and fall, leaves had about as much influence as stems on the average moisture content of the whole plant because of the increased proportion of leaf tissue.

The initiation of new foliage in the spring seemed to be correlated with the rapid buildup in moisture content of the whole plant. Both began at about the same time.

The seasonal patterns of variation in moisture content observed in gallberry, swamp cyrilla, redbay, and switch cane generally agree with Wendel and Storey's earlier study in 1959.

Apparently, substantial diurnal variation in moisture can occur in the foliage tissue of gallberry, swamp cyrilla, fetterbush, and honeycup, at least under the weather conditions existing at the time of observation.

U. S. Forest Service Research Paper SE-34 April 1968

Wood Density Surveys of the Minor Species of Yellow Pine in the Eastern United States

Part I - Spruce pine (*Pinus glabra* Walt.)

by

M. A. Taras and J. R. Saucier

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U. S. Department of Agriculture - Forest Service

Wood Density Surveys of the Minor Species of Yellow Pine in the Eastern United States

Part I — Spruce pine (*Pinus glabra* Walt.)

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INTRODUCTION

The first regionwide survey of wood density was made in 1955 in conjunction with the Forest Survey Inventory of Mississippi conducted by the Southern Forest Experiment Station in cooperation with the Forest Products Laboratory, Madison, Wisconsin. Results of this survey were reported by Mitchell and Wheeler in 1959 and by Wheeler and Mitchell in 1962. The useful information obtained from this survey stimulated the expansion of this type of work to a nationwide survey of wood density in cooperation with industry and other Forest Service Experiment Stations. The survey work, done over the past 10 years, has resulted in eight major publications. Two of these reports published in 1965 by the Forest Products Laboratory—"Western Wood Density Survey" and "Southern Wood Density Survey"—summarize the data obtained for the major commercially important species of the respective regions. These surveys yielded only fragmentary density data on some of the minor species of yellow pine, such as spruce pine (*Pinus glabra* Walt.), sand pine (*Pinus clausa* (Chapm.) Vasey), pond pine (*Pinus serotina* Michx.), pitch pine (*Pinus rigida* Mill.), Table-Mountain pine (*Pinus pungens* Lamb.), and Virginia pine (*Pinus virginiana* Mill.). There were several reasons for this: (1) the relatively small volumes of these species in comparison to the major yellow pine species, (2) the scattered distribution patterns of these minor species throughout their natural ranges, and (3) the low level of sampling, or no sampling at all, in some of the states where no surveys were conducted.

The need for additional raw material by expanding wood using industries in the South, the lack of wood density information on the minor species of yellow pine, and the inability to obtain the needed data through regular Forest Survey inventories stimulated the establishment of this study.

The study was conducted cooperatively by the Southeastern, Southern, and Northeastern Forest Experiment Stations and the Forest Products Laboratory of the U. S. Forest Service and industry. Field and laboratory work and the analysis of data were done by personnel of the Southeastern Forest Experiment Station located at the Forestry Sciences Laboratory, Athens, Georgia.

This report is the first in a series of reports to be published as data become available on the respective minor species listed earlier.

SURVEY OBJECTIVES

The objectives of the survey were as follows:

(1) To obtain data that will provide an estimate of the average specific gravity of unextracted and extracted wood of each minor species, and establish the degree of variation about each mean.

(2) To evaluate increment core/tree specific gravity relationships and develop regression equations for predicting tree specific gravity from increment core specific gravity.

(3) To examine the geographic trends of wood specific gravity within the range of each species, from east to west and from north to south.

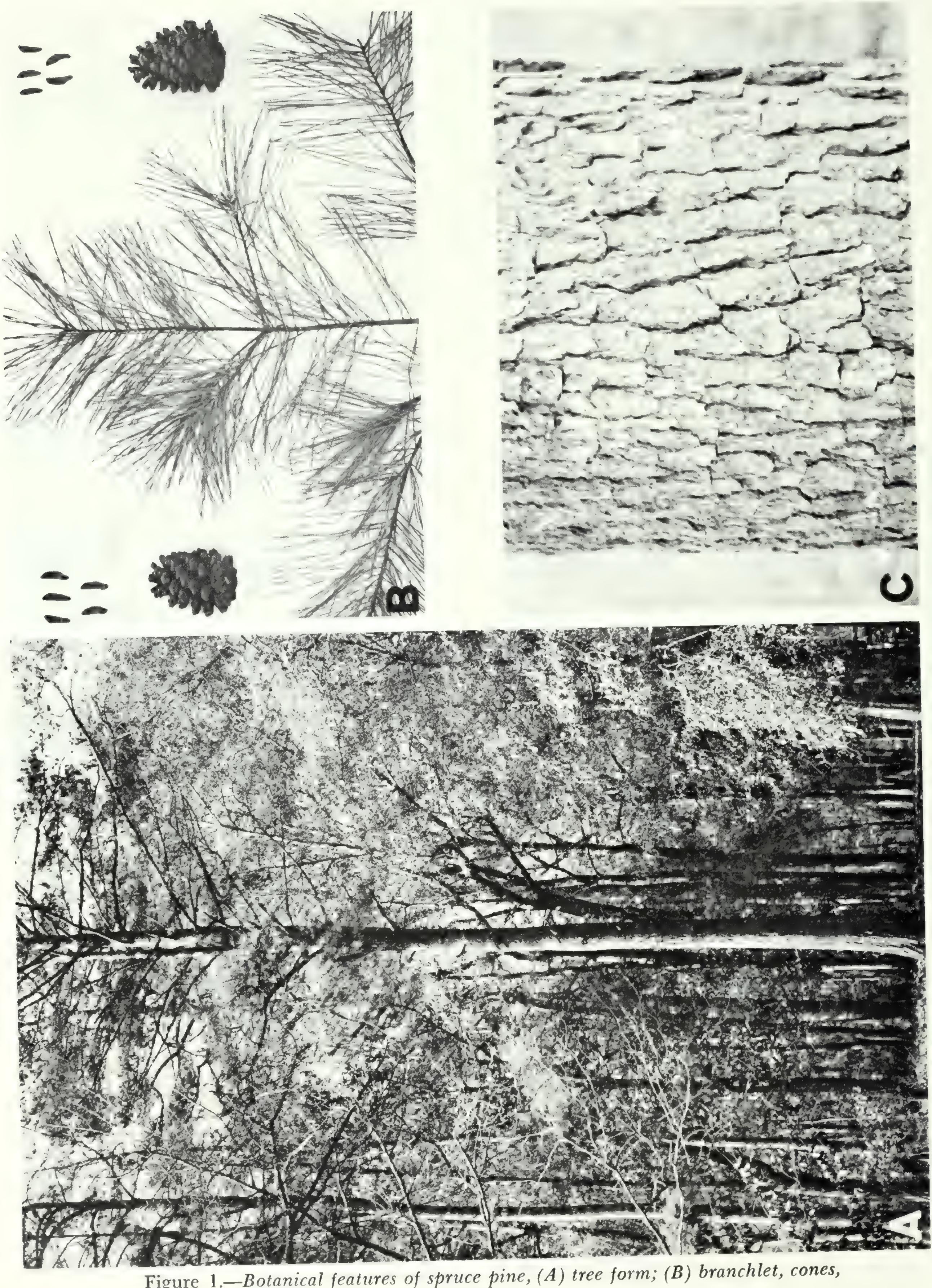

Figure 1.—*Botanical features of spruce pine, (A) tree form; (B) branchlet, cones, and seed; (C) bark of mature tree.*

MATERIALS AND METHODS

Species

Spruce pine (*Pinus glabra* Walt.) is the only species discussed in this report. This pine is described by Harlow and Harrar (1941) as having 2 slender, flexible needles about 2 to 3 inches long. Its cones are similar to those of shortleaf pine (*Pinus echinata*), but more nearly globose and frequently smaller, with minute weak prickles. Terminal buds are very small and thin. The crown has a lacey appearance because of the sparseness of needles. The bark on an old tree is dark gray, closely furrowed with narrow ridges, and appears similar to that of white pine, black oak, or gum (Figure 1).

Spruce pine has been classed as a medium-size tree, 80 to 90 feet high, and 2 to 2½ feet in diameter. Trees as high as 120 feet and 3½ feet in diameter have been reported.

It occurs as a scattered tree mixed with hardwood, or occasionally in pine stands on moist, fresh, sandy loams along river bottoms and low areas that occasionally become inundated. It is generally associated with such hardwoods as magnolia, red gum, beech, elm, hickory, and pines, such as shortleaf and loblolly. It is more shade tolerant than the other southern pines but not as tolerant as its hardwood associates. Best development occurs in warm, humid climates.

The range of this species extends from the south coastal plain of South Carolina southward to northwest Florida and west-

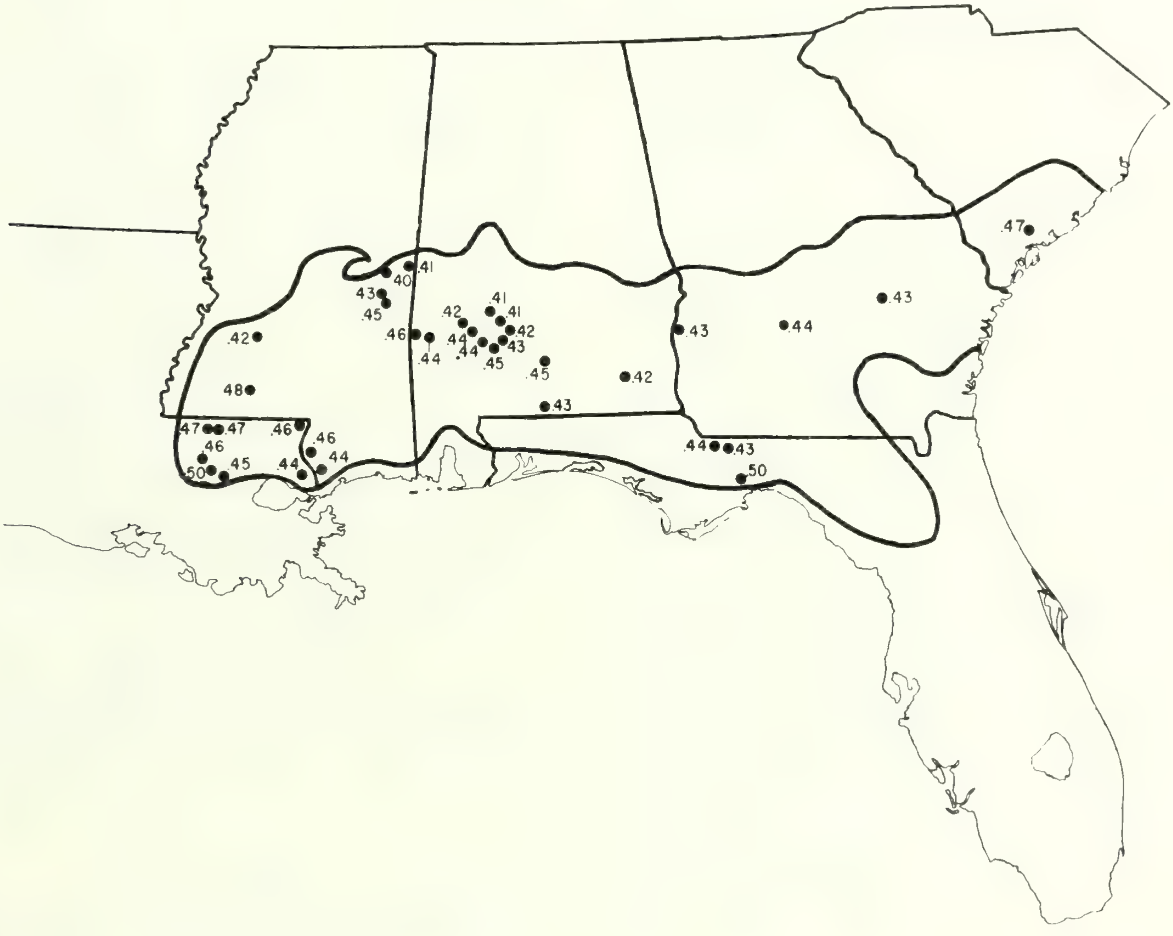

Figure 2.—*Range of spruce pine. Dots indicate location of sample plots; numbers indicate the average increment core specific gravity per plot.*

ward to the Mississippi River (range shown in Figure 2 from Critchfield and Little 1966).

Forest Survey reports of the Southern and Southeastern Forest Experiment Stations list the total predicted volume of growing stock of this species to be 404.9 million cubic feet, with the largest concentration of volume in Alabama, Mississippi, and Louisiana (328.8 million cubic feet, or 81 percent of the total volume).

General Field Sampling Procedure

A sample of 35 plots to be taken throughout the range of the species was arbitrarily set to meet the objective of the study. The number of trees to be taken per plot was calculated to be 33, in order to obtain an estimate of the mean wood density with a 95 percent confidence interval width of .02. The total number of trees sampled, therefore, was 1155. The plots were selected randomly, with replacement, with the probability roughly proportioned to the volume of the species within counties containing spruce pine. After a plot was assigned to a county, it was located within the county by random selection of paired grid coordinates that were on one-mile centers. At each plot location, a random azimuth was selected along which the first 33 trees were chosen as sample trees and from which two increment cores were taken from diametrically opposite sides of each tree. Increment cores were stored in a 4 percent solution of formaldehyde immediately after being removed from the tree and were shipped in a green condition to the laboratory. The starting point of the core sampling also served as plot center for random selection of two trees to be used for analyzing increment core/tree specific gravity relationships. Using a 3.03 diopter prism and starting with a north sighting, we selected the first two trees picked up in the prism when turning clockwise from north as sample trees. Two increment cores were taken from each of these trees before they were felled. Beginning at the butt end of the tree, one-inch thick disks were cut at every 5-foot interval to a 4-inch top. Total height, d.b.h., crown length, and diameter of each disk was recorded.

Laboratory Procedures

The specific gravity of all increment cores in an unextracted and extracted condition was determined by the maximum moisture content method described by Smith (1954). All cores were subjected to a vacuum treatment for several days to insure complete water saturation. Wood disks were soaked for several days and their specific gravities were determined by the buoyancy method described by Heinrichs (1954). The results are based on green volume and oven-dry weight.

Increment cores from all trees were extracted following the unextracted specific gravity determination. These extractions were made in a Soxhlet extractor with a mixture of two parts benzene and one part ethyl alcohol for a period of 24 hours. Following extraction, the cores were dried, saturated with water, and their specific gravities were determined by the maximum moisture method. No wood disks were extracted.

From the sample of trees collected to analyze increment core-tree specific gravity relationships, the increment cores were divided into 3 equal parts and the specific gravity was determined for each segment. This was done to obtain a weighted increment core specific gravity, and to examine the relationship of only parts (1/3 and 2/3) of increments to total tree specific gravity. Complete weighted core specific gravity was determined by weighting the segment specific gravities by the cross sectional areas the segments represented.

The average specific gravity of the individual 5-foot bolts within each tree was computed as the mean of its terminal disks. The average specific gravity of the tree was determined by weighting the average bolt specific gravity by bolt volume. Formulas for all computations are listed at the end of this report.

DATA ANALYSIS

The tree/increment core relationships analyzed in this study with tree specific gravity as the dependent variable in each case are as follows:

Simple Linear Regression Analysis

(1) Tree specific gravity on the specific gravity of a single increment core and on the average specific gravity of two increment cores taken at breast height. These relationships were developed with cores in the extracted and unextracted condition.

(2) Tree specific gravity on the specific gravity of a single weighted increment core, and the average of two weighted increment cores, in the extracted and unextracted condition.

(3) Tree specific gravity on the specific gravity of the outer one-third, and the outer two-thirds of a single increment core as well as the average specific gravity of the outer one-third and two-thirds of two increment cores in the extracted and unextracted condition.

Multiple Regression Analysis

In addition to the simple linear relationships, a series of multiple regression analyses were conducted in which measured tree characteristics were analyzed to establish their effect on the precision of predicting tree specific gravity. The variables included in the analyses were:

y = tree specific gravity
x_1 = single increment core specific gravity
x_2 = average weighted specific gravity of two cores
x_3 = diameter breast height (d.b.h.)
x_4 = d.b.h./age
x_5 = age
x_6 = 1/age
x_7 = volume/age
x_8 = total height
x_9 = total height/age

Other Regression Analysis

The relationship between extracted and unextracted increment core specific gravity was examined and an equation for predicting extracted from unextracted specific gravity was developed.

Computational procedures for computing the means and standard errors are shown at the end of this report.

RESULTS

Spruce Pine Specific Gravity and Its Variation

The average specific gravity of unextracted spruce pine increment cores, based on the mean value of two whole increment cores from 1152 sample trees collected over the entire range of the species, was .443. The standard error of the mean was .004, whereas the standard deviation of individual observations about the mean was .041.

In the extracted condition, these same increment cores had an average specific gravity of .415, with a standard error about the mean of .003 and a standard deviation of individuals about this mean of .034. This constitutes an average drop in specific gravity of 6.75 percent. The average specific gravity of extracted and unextracted increment cores by individual sample plots is shown in Table 1.

Past research has shown that specific gravity of increment cores taken at d.b.h. is higher than the specific gravity of the whole tree computed from disk samples taken at 5-foot intervals up the tree. When the specific gravity of the 1152 trees sampled by increment cores was adjusted through regression for whole tree gravity, the average specific gravity decreased from .443 to .426, with a standard error about the mean of .002 and a standard deviation for individuals of .028. The predicted tree specific gravities were obtained from the following regression equation:

$$\text{Tree specific gravity } (y) = 0.15830 + 0.64675 \text{ (specific gravity, two extracted cores)} - 0.04761 \left(\frac{\text{d.b.h.}}{\text{age}}\right)$$

The specific gravity of unextracted increment cores and the estimated tree specific gravity by three diameter classes (3.0"-8.9", 9.0"-14.9", and 15" +) are presented in Table 2 for each Forest Survey Unit sampled in this survey.

The data in Tables 1 and 2 are also shown in Figures 2, 3, and 4 to illustrate specific gravity changes with geographic location. It is obvious from these figures that there are no clearly apparent east-west, or north-south trends in specific gravity, as has been shown for other yellow pine species. The data indicate that some differences in specific gravity between coastal and inland spruce pine do exist. In Figure 2, for instance, where the average specific gravity values for each plot are shown, the plots near the coast average higher than those inland. The plots in South Carolina, Florida, southern Mississippi, and eastern Louisiana show specific gravity ranging from .44 to .50, whereas the inland plots have values from .40 to .46.

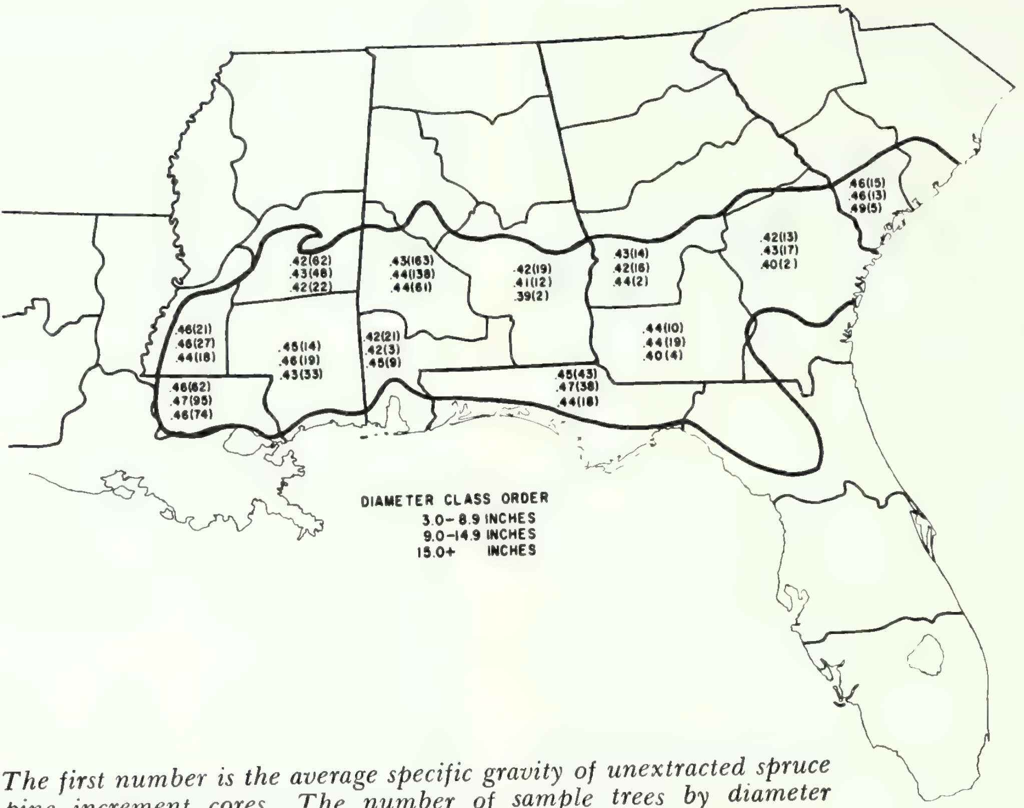

Figure 3.—*The first number is the average specific gravity of unextracted spruce pine increment cores. The number of sample trees by diameter classes within survey units is shown in parentheses.*

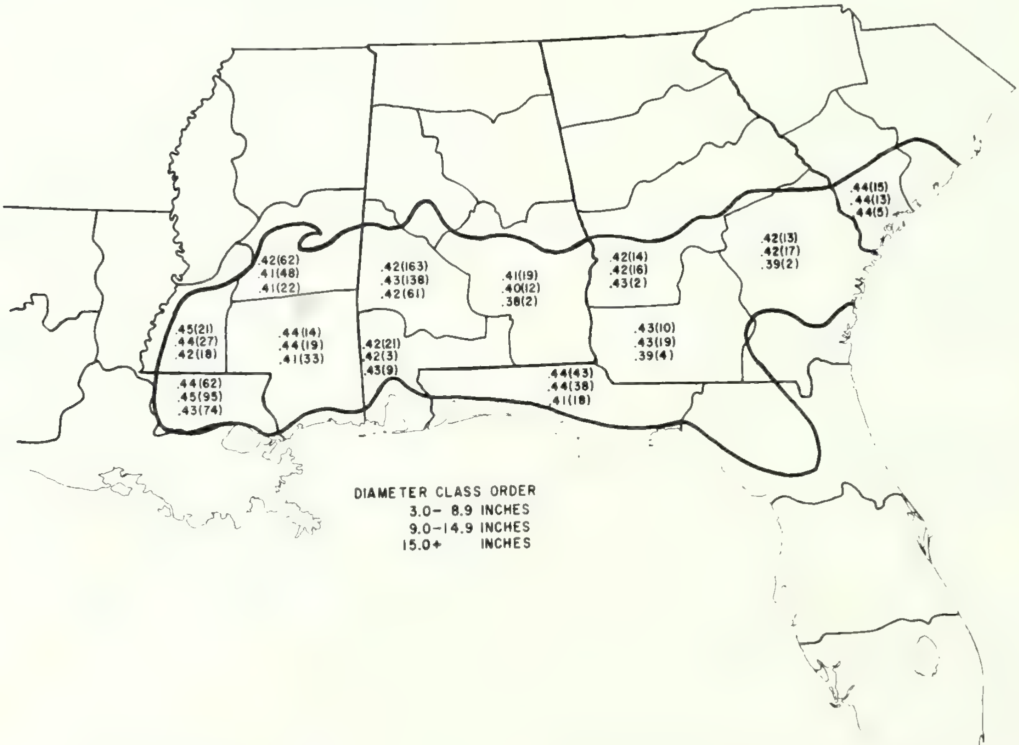

Figure 4.—*Tree specific gravity of spruce pine by diameter classes within survey units.*

The small change in specific gravity and the relative uniformity of the specific gravity averages over the entire range of the species may be associated with the restricted site requirements of spruce pine. It grows in low bottomland areas, near rivers and streams, and not over a wide variety of sites as the major yellow pines do. Moisture is generally not a limiting factor for its growth because of its occurrence near rivers and streams. Because moisture availability is associated with the amount of summerwood produced (which in turn affects specific gravity), it is reasonable to surmise that the uniformity in specific gravity over the range of the species is due, at least in part, to the relatively uniform conditions under which it grows. The differences in specific gravity which occur between plots (Figure 2) were not extremely large, but were statistically significant at the 0.1 percent probability level. Analyses of variance showing the mean squares and F-ratio are presented in Table 3.

Increment Core / Tree Specific Gravity Relationships—Simple Linear Regression Analysis

The increment core/tree specific gravity relationships examined by simple linear regressions are listed in Table 4, together with the correlation coefficients, the coefficients of determination, and standard errors about regression. These data show that some improvement in the correlations can be realized by the use of two increment cores over the use of only one core. When comparing one and two increment core equations in all sets of conditions examined, the percent of variation about regression accounted for by two increment cores is from 3 to 16 percent higher than that found for single core samples. Single increment core relationships accounted for 52 to 66 percent of the variation about regression, whereas two cores explained between 56 and 74 percent. Weighting a single increment core, as well as weighting two increment cores, showed an improvement of 3-5 percent in the coefficient of determination.

The weighted specific gravity of two extracted increment cores gave the best relationship of all those examined by linear analysis. The correlation coefficient for this relationship was 0.86, with a standard error about regression of .015. In general, extractives in increment cores had little influence on the relationship. In the partial increment core/tree specific gravity relationships, the outer two-thirds of cores had the same degree of association as the weighted increment cores with tree specific gravity. One exception was the relationship of the outer two-thirds of one extracted core and whole tree specific gravity where only 55 percent of the variation was explained. The reason for this exception is not apparent. The outer one-third of increment cores gave the poorest relationship with tree specific gravity. It explained only 52 to 66 percent of the variation about regression. The results obtained for these relationships are in general agreement with those obtained by Taras and Wahlgren (1963) for similar relationships analyzed for slash and longleaf pine.

Tree / Increment Core Specific Gravity Relationships—Multiple Regression Analysis

The multiple regression analysis was made to determine if such factors as d.b.h., age, 1/age, volume/age, total height, and total height/age gave improvement over the simple relationships presented earlier.

A stepwise multiple regression was used to analyze the effect of the independent variables just listed. The results are presented in Table 5. Correlation coefficients, coefficients of determination, and standard error about regression are listed for the linear regressions, as well as the "best" two and three variable regressions. It can be seen from this table that little improvement is realized in most cases by the introduction of other variables into the equations. There were only two cases in which a 10 percent increase in the coefficients of determination was obtained. These occurred in the relationships involving one increment core in the extracted and in the unextracted condition. These required the addition of two independent variables to the equation. In most cases, the addition of a third variable to the equation gave little improvement. The best equation developed from these data for predicting tree specific gravity was:

$$y = 0.16980 + 0.60976 \text{ (weighted sp. gr., two extracted cores)} - 0.04808 \left(\frac{\text{d.b.h.}}{\text{age}}\right)$$

This relationship had a correlation coefficient of 0.88 and accounted for 77 percent of the variation about regression. All the equations developed for predicting tree specific gravity are shown in Table 6 with their correlation coefficients, coefficients of determination, and standard errors. The equations are listed in the order of their precision in predicting tree specific gravity.

The following equation,

$$y = 0.15830 + 0.64675 \text{ (sp. gr., two extracted cores)} - 0.04761 \left(\frac{\text{d.b.h.}}{\text{age}}\right),$$

was used in this study to adjust increment core specific gravities to tree specific gravities. This equation was used instead of the best one developed because of the time and increased cost involved in obtaining weighted specific gravity values for segmented cores. The equation used had a correlation coefficient of .86 and accounted for 74 percent of the variation about regression, which is only 3 percent less than accounted for by the best equation.

Relationship of Extracted to Unextracted Specific Gravity

The specific gravity of all increment cores was determined in both the extracted and unextracted condition. These data were analyzed by linear regression. The results show a high correlation ($r = .88$) for the relationship between extracted and unextracted increment core specific gravity which accounted for 77 percent of the total variation. The equation for this relationship is:

$$y = 0.05813 + 0.80477x$$

where: y = extracted core specific gravity
x = unextracted core specific gravity.

The extracted core specific gravity, as mentioned earlier, was 6.75 percent lower than the average unextracted specific gravity. These results for spruce pine are similar to those shown by Taras and Saucier (1967) for shortleaf and loblolly pine.

SUMMARY AND CONCLUSIONS

The average specific gravity of spruce pine increment cores taken at d.b.h. was .443. In the extracted condition, these same cores had an average specific gravity of .415, a decrease of about 6.75 percent as a result of extraction. Extracted specific gravity of increment cores can be computed by the following linear equation:

$$y = 0.05813 + 0.80477 \text{ (unextracted specific gravity).}$$

Spruce pine tree specific gravity adjusted from increment cores through regression averaged .426, a decrease of about 4 percent in average specific gravity from the average computed for increment cores.

There appears to be no distinct north-south or east-west geographic trends in specific gravity of spruce pine. Sample plots near the coast had the highest specific gravity, whereas inland plots were lower.

In the increment core-tree specific gravity relationships studied, solvent extraction of two increment cores reduced the unexplained variation over that of two unextracted cores, but extraction of one increment core did not. A small degree of improvement was realized in the relationship by using two increment cores rather than one and by weighting the three equal parts of each increment core by the cross sectional area they represented. Portions of cores—that is, the outer two-thirds of an increment core—predicted tree specific gravity about equally as well as the weighted whole increment cores. The best equation developed involved two independent variables—(1) the weighted specific gravity of two extracted increment cores, and (2) d.b.h./age, and explained 77 percent of the variation.

Increment core specific gravities were adjusted to tree specific gravities by the following equation:

$$y = 0.15830 + 0.64675 \text{ (sp. gr., two extracted cores)} - 0.04761 \left(\frac{\text{d.b.h.}}{\text{age}}\right)$$

which explained 74 percent of the variation.

Computational Procedures

1. Increment core specific gravity =

$$\frac{\text{ovendry weight of core}}{\text{green weight of core} - .3464\,(\text{ovendry weight of core})}$$

2. Disk specific gravity =

$$\frac{\text{ovendry weight of disk}}{\text{displaced volume of disk}}$$

3. Bolt specific gravity =

$$\frac{\text{specific gravity top disk} + \text{specific gravity bottom disk}}{2}$$

4. Tree specific gravity =

$$\frac{\sum_{1-n} (\text{bolt volume x bolt specific gravity})}{\sum_{1-n} \text{bolt volumes}}$$

5. Bolt volume =

$$\text{bolt length, feet x} \left[\frac{.005454(\text{d.i.b.})_t^2 + .005454(\text{d.i.b.})_b^2}{2}\right]$$

where: t = top of bolt

b = base of bolt

6. (a) Mean core specific gravity $\bar{x} = \dfrac{\Sigma_i \Sigma_j \; x_{ij}}{m_1 n_1}$

where: x_{ij} = the core gravity for the jth tree at the ith location

m_1 = number of trees at each location

n_1 = number of locations

(b) The standard error of the core mean is approximated by:

$$\text{standard error } (\bar{x}) = \sqrt{\frac{S_B^2}{m_1 n_1}}$$

where: S_B^2 = variance of core gravities between locations

(c) The standard deviation of individuals was estimated from the sample range of the core gravities using the tabular values of the ratio of the standard deviation to the range.

7. Tree specific gravities were estimated from regression by:

(a) Tree specific gravity $(Y) = b_0 + b_1x_1 + b_2x_2$

where: Y = tree specific gravity

x_1 = average specific gravity of 2 extracted cores

x_2 = d.b.h./age

(b) The standard error of the predicted mean tree gravity was estimated by--

$$S_{\hat{y}} = \left[S^2_{y.x} \left(\frac{1}{m_2n_2} + C_{11} (\bar{x}_{1,1} - \bar{x}_{1,2})^2 + C_{22} (\bar{x}_{2,1} - \bar{x}_{2,2})^2 + 2C_{12} (\bar{x}_{1,1} - \bar{x}_{1,2})(\bar{x}_{2,1} - \bar{x}_{2,2}) \right) + \frac{S^2_y}{m_1n_1} \right]^{\frac{1}{2}}$$

where: $S^2_{y.x}$ = residual mean squares

S^2_y = variance of y prior to adjustment for regression

$\bar{x}_{1,1}$ = mean core gravity of trees from which only cores were collected, sample (1)

$\bar{x}_{1,2}$ = mean core gravity of trees collected for tree-core relationships, sample (2)

$\bar{x}_{2,1}$ = mean d.b.h./age for sample (1)

$\bar{x}_{2,2}$ = mean d.b.h./age for sample (2)

m_1 = number of trees at each location, sample (1)

m_2 = number of trees at each location, sample (2)

n_1 = number of locations, sample (1)

n_2 = number of locations, sample (2)

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Table 1.—*Unextracted and extracted increment core specific gravity of spruce pine sample plots.*

Plot number	County and state	Sample size	Unextracted		Extracted		Difference
			Mean and standard error	Standard deviation	Mean and standard error	Standard deviation	
		Number					*Percent*
1	Colletin, S. C.	33	.468 (.005)	.029	.445 (.004)	.023	5.17
2	Wheeler, Ga.	32	.428 (.004)	.025	.412 (.004)	.025	3.88
3	Worth, Ga.	33	.437 (.005)	.030	.418 (.005)	.031	4.55
4	Quitman, Ga.	32	.427 (.007)	.039	.407 (.006)	.035	4.91
5	Wakulla, Fla.	33	.495 (.008)	.045	.476 (.007)	.042	3.99
6	Gadsden, Fla.	33	.440 (.005)	.030	.425 (.005)	.030	3.53
7	Gadsden, Fla.	33	.434 (.006)	.037	.418 (.006)	.035	3.83
8	Coffee, Ala.	33	.415 (.005)	.030	.396 (.005)	.031	4.80
9	Escambia, Ala.	33	.431 (.005)	.032	.413 (.005)	.030	4.36
10	Conecuh, Ala.	33	.454 (.007)	.038	.431 (.006)	.031	5.34
11	Monroe, Ala.	32	.454 (.006)	.033	.435 (.006)	.032	4.37
12	Monroe, Ala.	33	.408 (.006)	.032	.391 (.005)	.031	4.35
13	Monroe, Ala.	33	.424 (.005)	.031	.393 (.004)	.025	7.89
14	Monroe, Ala.	33	.434 (.006)	.036	.396 (.005)	.029	9.60
15	Wilcox, Ala.	33	.411 (.005)	.026	.388 (.004)	.026	5.92
16	Clarke, Ala.	33	.440 (.006)	.036	.414 (.005)	.030	6.28
17	Clarke, Ala.	33	.442 (.004)	.026	.408 (.004)	.021	8.33
18	Clarke, Ala.	33	.421 (.007)	.039	.393 (.005)	.031	7.12
19	Choctaw, Ala.	33	.436 (.006)	.037	.407 (.006)	.033	7.13
20	Choctaw, Ala.	33	.457 (.007)	.040	.418 (.006)	.033	9.33
21	Clarke, Miss.	33	.428 (.007)	.039	.401 (.006)	.035	6.73
22	Clarke, Miss.	33	.449 (.006)	.037	.425 (.006)	.035	5.65
23	Lauderdale, Miss.	33	.400 (.004)	.021	.385 (.004)	.022	3.90
24	Lauderdale, Miss.	33	.412 (.006)	.034	.384 (.004)	.025	7.29
25	Hancock, Miss.	33	.437 (.005)	.028	.403 (.005)	.027	8.44
26	Pearl River, Miss.	33	.455 (.006)	.034	.415 (.005)	.032	9.64
27	Pike, Miss.	33	.480 (.006)	.037	.436 (.006)	.033	10.09
28	Copiah, Miss.	33	.425 (.005)	.027	.396 (.004)	.025	7.32
29	Washington, La.	33	.458 (.005)	.028	.426 (.004)	.026	7.51
30	St. Tammany, La.	33	.445 (.004)	.024	.410 (.004)	.025	8.54
31	Livingston, La.	33	.454 (.005)	.031	.422 (.005)	.028	7.58
32	Livingston, La.	33	.495 (.008)	.045	.451 (.006)	.037	9.76
33	Livingston, La.	33	.462 (.006)	.035	.423 (.005)	.029	9.22
34	St. Helena, La.	33	.467 (.007)	.038	.432 (.006)	.034	8.10
35	E. Feliciana, La.	33	.470 (.007)	.039	.433 (.006)	.032	8.55
Total		1152	.443 (.004)	.041	.415 (.003)	.034	6.75

Table 2.—*Specific gravity data for spruce pine by States and by forest survey units within States.*

State, survey unit and number	Locations sampled	Diameter class	Trees sampled	Unextracted increment core specific gravity		Estimated tree[1] specific gravity mean and standard error	Approx.[2] timber volume
				Mean and standard error	Standard deviation		
	Number	*Inches*	*Number*				*Million cu. ft.*
Alabama							
Southwest-S (1)	1	3.0— 8.9	21	.425 (.007)	.034	.419 (.007)	1.5
		9.0—14.9	3	.424 (.017)	.028	.416 (.017)	5.1
		15.0 +	9	.447 (.006)	.019	.431 (.010)	4.2
Southwest-N (2)	11	3.0— 8.9	163	.429 (.003)	.036	.422 (.003)	8.6
		9.0—14.9	138	.439 (.003)	.035	.426 (.001)	47.5
		15.0 +	61	.440 (.005)	.035	.421 (.006)	49.8
Southeast (3)	1	3.0— 8.9	19	.421 (.007)	.029	.414 (.010)	5.5
		9.0—14.9	12	.410 (.006)	.022	.400 (.009)	15.7
		15.0 +	2	.393 (.034)	.049	.381 (.021)	10.8
State Total	13	3.0— 8.9	203	.428 (.002)	.034	.421 (.003)	15.6
		9.0—14.9	153	.436 (.003)	.033	.424 (.003)	63.2
		15.0 +	72	.440 (.004)	.034	.422 (.003)	64.8
Florida							
Northwest (2)	3	3.0— 8.9	43	.453 (.006)	.044	.438 (.005)	3.3
		9.0—14.9	38	.469 (.008)	.051	.444 (.006)	13.8
		15.0 +	18	.438 (.010)	.043	.412 (.009)	12.9
State Total	Same as above						
Georgia							
Southeast (1)	1	3.0— 8.9	13	.425 (.006)	.024	.420 (.009)	2.6
		9.0—14.9	17	.433 (.005)	.022	.416 (.008)	3.6
		15.0 +	2	.405 (.025)	.036	.394 (.021)	10.3
Southwest (2)	1	3.0— 8.9	10	.441 (.008)	.030	.432 (.010)	3.1
		9.0—14.9	19	.443 (.007)	.029	.427 (.007)	8.1
		15.0 +	4	.395 (.009)	.017	.391 (.015)	—
Central (3)	1	3.0— 8.9	14	.428 (.010)	.036	.424 (.008)	0.9
		9.0—14.9	16	.424 (.012)	.049	.418 (.008)	3.0
		15.0 +	2	.443 (.009)	.013	.430 (.021)	1.8
State Total	3	3.0— 8.9	37	.430 (.005)	.029	.425 (.005)	6.6
		9.0—14.9	52	.434 (.005)	.039	.420 (.005)	14.7
		15.0 +	8	.410 (.009)	.027	.402 (.011)	12.1
Louisiana							
Southeast (4)	7	3.0— 8.9	62	.463 (.005)	.041	.442 (.004)	12.4
		9.0—14.9	95	.472 (.004)	.042	.446 (.004)	29.5
		15.0 +	74	.455 (.003)	.024	.430 (.005)	41.6
State Total	Same as above						
Mississippi							
Central (3)	4	3.0— 8.9	62	.420 (.005)	.038	.415 (.004)	6.0
		9.0—14.9	48	.427 (.006)	.039	.411 (.005)	17.6
		15.0 +	22	.419 (.008)	.036	.406 (.007)	14.4
South (4)	2	3.0— 8.9	14	.450 (.009)	.034	.436 (.008)	1.9
		9.0—14.9	19	.464 (.006)	.025	.437 (.008)	2.8
		15.0 +	33	.433 (.005)	.029	.409 (.007)	6.3
Southwest (5)	2	3.0— 8.9	21	.458 (.009)	.041	.446 (.007)	8.0
		9.0—14.9	27	.458 (.007)	.039	.441 (.006)	22.6
		15.0 +	18	.439 (.009)	.038	.424 (.007)	17.0
State Total	8	3.0— 8.9	97	.432 (.004)	.037	.425 (.004)	15.9
		9.0—14.9	94	.444 (.004)	.044	.425 (.004)	43.0
		15.0 +	73	.430 (.004)	.035	.412 (.005)	37.7
South Carolina							
S. Coastal Plain (1)	1	3.0— 8.9	15	.464 (.005)	.020	.443 (.008)	2.5
		9.0— 14.9	13	.465 (.008)	.028	.435 (.009)	3.9
		15.0 +	5	.488 (.016)	.035	.442 (.015)	6.3
State Total	Same as above						
All States	35	3.0— 8.9	457	.437 (.002)	.036	.427 (.002)	56.3
		9.0—14.9	445	.449 (.002)	.039	.431 (.003)	169.1
		15.0 +	250	.442 (.002)	.031	.420 (.004)	175.4
OVERALL TOTAL	35	All classes	1152	.443 (.004)	.041	.426 (.002)	400.8

[1] Estimates were made using the following equation:
$y = 0.15830 + 0.64675$ (sp. gr., two extracted cores) $- 0.04761$ (d.b.h./age).

[2] From Forest Survey releases of the Southern and Southeastern Experiment Stations.

Table 3.—*Analysis of variance for spruce pine specific gravity and test of significance for locations.*

Source	d.f.	Unextracted ms	Extracted ms
Locations	34	0.01768190***	0.01376202***
Within locations	1117	0.00114697	0.00075840
Total	1151		

***Significant at the 0.1 percent probability level.

Table 4.—*Correlation coefficients, standard error, and coefficients of determination for single and multiple, weighted and unweighted increment core/tree specific gravity relationship, and partial increment core/tree specific gravity relationship for spruce pine.*

Relationships	r	r^2	Standard error
Tree specific gravity on:			
Specific gravity, 1 core	0.78	0.61	0.019
Specific gravity, 2 cores	0.81	0.66	0.017
Specific gravity, 1 extracted core	0.78	0.61	0.018
Specific gravity, 2 extracted cores	0.84	0.71	0.016
Weighted specific gravity, 1 core	0.81	0.66	0.018
Weighted specific gravity, 2 cores	0.84	0.71	0.016
Weighted specific gravity, 1 extracted core	0.80	0.64	0.018
Weighted specific gravity, 2 extracted cores	0.86	0.74	0.015
Specific gravity, outer 2/3 of 1 core	0.81	0.66	0.017
Specific gravity, outer 2/3 of 2 cores	0.83	0.69	0.016
Specific gravity, outer 2/3 of 1 extracted core	0.74	0.55	0.020
Specific gravity, outer 2/3 of 2 extracted cores	0.84	0.71	0.016
Specific gravity, outer 1/3 of 1 core	0.72	0.52	0.020
Specific gravity, outer 1/3 of 2 cores	0.78	0.61	0.019
Specific gravity, outer 1/3 of 1 extracted core	0.73	0.53	0.020
Specific gravity, outer 1/3 of 2 extracted cores	0.75	0.56	0.020

Table 5.—*Correlation coefficients, standard errors, and coefficients of determination for the linear regressions, and the best two and three variable regressions for spruce pine tree-core specific gravity relationships.*

Relationships	r	r^2	Standard error
Tree specific gravity on:			
Specific gravity, 1 core	0.78	0.61	0.019
Specific gravity, 1 core + d.b.h.	0.81	0.66	0.018
Specific gravity, 1 core + d.b.h + merch. vol.	0.84	0.71	0.016
Specific gravity, 2 cores	0.81	0.66	0.017
Specific gravity, 2 cores + d.b.h.	0.82	0.67	0.017
Specific gravity, 2 cores + d.b.h. + total height	0.83	0.69	0.017
Specific gravity, 1 extracted core	0.78	0.61	0.018
Specific gravity, 1 extracted core + d.b.h./age	0.81	0.66	0.018
Specific gravity, 1 extracted core + d.b.h./age + merch. vol.	0.81	0.66	0.018
Specific gravity, 2 extracted cores	0.84	0.71	0.016
Specific gravity, 2 extracted cores + d.b.h./age	0.86	0.74	0.015
Specific gravity, 2 extracted cores + d.b.h./age + age	0.86	0.74	0.015
Weighted specific gravity, 1 core	0.81	0.66	0.018
Weighted specific gravity, 1 core + d.b.h./age	0.83	0.69	0.017
Weighted specific gravity, 1 core + d.b.h./age + 1/age	0.84	0.71	0.016
Weighted specific gravity, 2 cores	0.84	0.71	0.016
Weighted specific gravity, 2 cores + d.b.h./age	0.85	0.72	0.016
Weighted specific gravity, 2 cores + d.b.h./age + total height	0.85	0.72	0.016
Weighted specific gravity, 1 extracted core	0.80	0.64	0.018
Weighted specific gravity, 1 extracted core + total height/age	0.83	0.69	0.017
Weighted specific gravity, 1 extracted core + total height/age + d.b.h./age	0.83	0.69	0.017
Weighted specific gravity, 2 extracted cores	0.86	0.74	0.015
Weighted specific gravity, 2 extracted cores + d.b.h/age	0.88	0.77	0.014
Weighted specific gravity, 2 extracted cores + d.b.h/age + total height/age	0.88	0.77	0.014
Specific gravity, outer 2/3 of 1 core	0.81	0.66	0.017
Specific gravity, outer 2/3 of 1 core + d.b.h./age	0.83	0.69	0.017
Specific gravity, outer 2/3 of 1 core + d.b.h./age + 1/age	0.84	0.71	0.017
Specific gravity, outer 2/3 of 2 cores	0.83	0.69	0.016
Specific gravity, outer 2/3 of 2 cores + d.b.h./age	0.85	0.72	0.016
Specific gravity, outer 2/3 of 2 cores + d.b.h./age + total height	0.85	0.72	0.016
Specific gravity, outer 2/3 of 1 extracted core	0.74	0.55	0.020
Specific gravity, outer 2/3 of 1 extracted core + 1/age	0.78	0.61	0.019
Specific gravity, outer 2/3 of 1 extracted core + 1/age + d.b.h./age	0.78	0.61	0.019
Specific gravity, outer 2/3 of 2 extracted cores	0.84	0.71	0.016
Specific gravity, outer 2/3 of 2 extracted cores + total height/age	0.87	0.76	0.015
Specific gravity, outer 2/3 of 2 extracted cores + total height/age + total height	0.87	0.76	0.015
Specific gravity, outer 1/3 of core	0.72	0.52	0.020
Specific gravity, outer 1/3 of core + d.b.h./age	0.77	0.59	0.019
Specific gravity, outer 1/3 of core + d.b.h./age + merch. vol.	0.78	0.61	0.019
Specific gravity, outer 1/3 of 2 cores	0.78	0.61	0.019
Specific gravity, outer 1/3 of 2 cores + age	0.81	0.66	0.018
Specific gravity, outer 1/3 of 2 cores + age + merch. vol./age	0.81	0.66	0.018
Specific gravity, outer 1/3 of 1 extracted core	0.73	0.53	0.020
Specific gravity, outer 1/3 of 1 extracted core + d.b.h./age	0.79	0.62	0.018
Specific gravity, outer 1/3 of 1 extracted core + d.b.h./age + merch. vol.	0.80	0.64	0.018
Specific gravity, outer 1/3 of 2 extracted cores	0.75	0.56	0.020
Specific gravity, outer 1/3 of 2 extracted cores + d.b.h./age	0.80	0.64	0.018
Specific gravity, outer 1/3 of 2 extracted cores + d.b.h./age + total height	0.81	0.66	0.018

Table 6.—*Regression equations, correlation coefficients, coefficient of determination, and standard errors about regressions for spruce pine increment core/tree specific gravity relationships.*

Regression equations	r	r2	Standard error
Tree specific gravity (y):			
y = 0.16980 + 0.60976 (weighted sp. gr., 2 extracted cores) — 0.04808 (d.b.h./age)	0.88	0.77	0.014
y = 0.16725 + 0.62234 (weighted sp. gr., 2 extracted cores) — 0.03424 (d.b.h./age) — 0.00410 (total height/age)	0.88	0.77	0.014
y = 0.18510 + 0.57987 (sp. gr., outer 2/3 of 2 extracted cores) — 0.01093 (total height/age)	0.87	0.76	0.015
y = 0.18681 + 0.55817 (sp. gr., outer 2/3 of 2 extracted cores) — 0.01186 (total height/age) + 0.00013 (total ht.)	0.87	0.76	0.015
y = 0.14371 + 0.63424 (weighted sp. gr., 2 extracted cores)	0.86	0.74	0.015
y = 0.15830 + 0.64675 (sp. gr., 2 extracted cores) — 0.04761 (d.b.h./age)	0.86	0.74	0.015
y = 0.16300 + 0.66544 (sp. gr., 2 extracted cores) — 0.06094 (d.b.h./age) — 0.0020 (age)	0.86	0.74	0.015
y = 0.15794 + 0.60688 (sp. gr., outer 2/3 of 2 cores) — 0.04626 (d.b.h./age)	0.85	0.72	0.016
y = 0.15194 + 0.62019 (weighted sp. gr., 2 cores) — 0.04378 (d.b.h./age)	0.85	0.72	0.016
y = 0.16070 + 0.59030 (sp. gr., outer 2/3 of 2 cores) — 0.04797 (d.b.h./age) + 0.00007 (total height)	0.85	0.72	0.016
y = 0.15422 + 0.60742 (weighted sp. gr., 2 cores) — 0.04511 (d.b.h./age) + 0.00005 (total height)	0.85	0.72	0.016
y = 0.13169 + 0.67360 (sp. gr., 2 extracted cores)	0.84	0.71	0.016
y = 0.17241 + 0.56363 (sp. gr., outer 2/3 of extracted cores)	0.84	0.71	0.016
y = 0.12490 + 0.64887 (weighted sp. gr., 2 cores)	0.84	0.71	0.016
y = 0.19298 + 0.61975 (sp. gr., 1 core) — 0.00566 (d.b.h.) + 0.00063 (merch. vol.)	0.84	0.71	0.016
y = 0.18721 + 0.53681 (sp. gr., outer 2/3 of 1 core) + 0.27148 (1/age) — 0.06327 (d.b.h./age)	0.84	0.71	0.017
y = 0.17726 + 0.56015 (weighted sp. gr., 1 core) + 0.38650 (1/age) — 0.07252 (d.b.h./age)	0.84	0.71	0.016
y = 0.13026 + 0.63494 (sp. gr., outer 2/3 of 2 cores)	0.83	0.69	0.016
y = 0.19597 + 0.52409 (sp. gr., outer 2/3 of 1 core) — 0.05048 (d.b.h./age)	0.83	0.69	0.017
y = 0.23081 + 0.47724 (weighted sp. gr., 1 extracted core) — 0.01135 (total height/age)	0.83	0.69	0.017
y = 0.13429 + 0.63963 (sp. gr., 2 cores) — 0.00214 (d.b.h.) + 0.00036 (total height)	0.83	0.69	0.017
y = 0.24030 + 0.45777 (weighted sp. gr., 1 extracted core) — 0.03018 (d.b.h./age) — 0.00654 (total height/age)	0.83	0.69	0.017
y = 0.12171 + 0.70001 (sp. gr., 2 cores) — 0.00126 (d.b.h.)	0.82	0.67	0.017
y = 0.16840 + 0.54911 (sp. gr., outer 2/3 of 1 core)	0.81	0.66	0.017
y = 0.12235 + 0.66260 (sp. gr., 2 cores)	0.81	0.66	0.017
y = 0.16123 + 0.56591 (weighted sp. gr., 1 core)	0.81	0.66	0.018
y = 0.15219 + 0.64537 (sp. gr., 1 core) — 0.00181 (d.b.h.)	0.81	0.66	0.018
y = 0.17747 + 0.48541 (sp. gr., outer 1/3 of 2 cores) + 0.00045 (age)	0.81	0.66	0.018
y = 0.23453 + 0.46852 (sp. gr., 1 extracted core) — 0.05271 (d.b.h./age)	0.81	0.66	0.018
y = 0.17775 + 0.49222 (sp. gr., outer 1/3 of 2 cores) — 0.00588 (merch. vol./age) + 0.00046 (age)	0.81	0.66	0.018
y = 0.23872 + 0.45763 (sp. gr., 1 extracted core) — 0.05753 (d.b.h./age) + 0.00006 (merch. vol.)	0.81	0.66	0.018
y = 0.23390 + 0.42999 (sp. gr., outer 1/3 of 2 extracted cores) — 0.06946 (d.b.h./age) + 0.00026 (total height)	0.81	0.66	0.018
y = 0.21753 + 0.46026 (weighted sp. gr., 1 extracted core)	0.80	0.64	0.018
y = 0.23330 + 0.47152 (sp. gr., outer 1/3 of 2 extracted cores) — 0.06550 (d.b.h./age)	0.80	0.64	0.018
y = 0.26072 + 0.40758 (sp. gr., outer 1/3 of 1 extracted core) — 0.07800 (d.b.h./age) + 0.00013 (merch. vol.)	0.80	0.64	0.018
y = 0.25497 + 0.42350 (sp. gr., outer 1/3 of 1 extracted core) — 0.06959 (d.b.h./age)	0.79	0.62	0.018
y = 0.15675 + 0.58334 (sp. gr., 1 core)	0.78	0.61	0.019
y = 0.18545 + 0.50906 (sp. gr., outer 1/3 of 2 cores)	0.78	0.61	0.019
y = 0.20737 + 0.49206 (sp. gr., 1 extracted core)	0.78	0.61	0.018
y = 0.29168 + 0.33379 (sp. gr., outer 2/3 of 1 extracted core) — 0.76370 (1/age)	0.78	0.61	0.019
y = 0.26006 + 0.38827 (sp. gr., outer 1/3 of 1 core) — 0.07459 (d.b.h./age) + 0.00013 (merch. vol.)	0.78	0.61	0.019
y = 0.29588 + 0.33038 (sp. gr., outer 2/3 of 1 extracted core) — 0.53319 (1/age) — 0.02740 (d.b.h./age)	0.78	0.61	0.019
y = 0.25397 + 0.40445 (sp. gr., outer 1/3 of 1 core) — 0.06598 (d.b.h./age)	0.77	0.59	0.019
y = 0.20268 + 0.49300 (sp. gr., outer 1/3 of 2 extracted cores)	0.75	0.56	0.020
y = 0.26163 + 0.35589 (sp. gr., outer 2/3 of 1 extracted core)	0.74	0.55	0.020
y = 0.22555 + 0.43873 (sp. gr., outer 1/3 of 1 extracted core)	0.73	0.53	0.020
y = 0.22232 + 0.42606 (sp. gr., outer 1/3 of 1 core)	0.72	0.52	0.020

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Multiple-Product Yield Estimates for Unthinned Slash Pine Plantations--Pulpwood, Sawtimber, Gum

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Multiple-Product Yield Estimates for Unthinned Slash Pine Plantations--Pulpwood, Sawtimber, Gum

by

Frank A. Bennett and Jerome L. Clutter[1]

Early control of stocking by management in southern pine forests is dictated by the fact that optimum growing space depends upon management objectives and financial policy. Although the amount and distribution of growing stock can be closely controlled through planting, the efforts of management may be only partially effective without information on multiple-product yields. It is well known that a wide spacing is needed in slash pine stands for optimum sawtimber and gum yields, whereas a close spacing is necessary to maximize pulpwood yields. If, however, the objective of management is to maximize returns in dollars and cents, some compromise between these two extremes may be required. Determining the optimum density and rotation age for this objective requires techniques for predicting multiple-product yields for various combinations of plantation age, site index, and stand density. This paper presents such information for old-field, unthinned slash pine plantations located south of the fall line in Georgia and in north and west Florida. Multiple-product yield tables are also presented, together with returns for various product combinations.

Yield estimates were developed by a diameter distribution analysis procedure which is particularly well suited to the solution of multiple-product yield problems. The method is certainly not restricted to multiple-product situations, however, and it displays certain advantages which recommend it for general application in predicting yields from even-aged stands.

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DIAMETER DISTRIBUTIONS

Multiple-product yield estimates are most conveniently derived from information on diameter distributions occurring in plantations of varying ages, site indices, and stand densities.

To establish diameter distributions, equations for predicting maximum and minimum diameters for any given age--site--density combination were first formulated by regression analyses of data from 478 plots located in the coastal plain of Georgia and north Florida. The distribution of trees between these two extremes of diameter was then determined by establishing a family of frequency distribution curves which defined the relative proportion of trees in each occupied diameter class as a function of age, site index (25-year basis), and density.[3]

At age 15 and with low stockings, the distribution encompasses six to eight diameter classes (table 1). The spread includes eight to eleven diameter classes at age 30. Higher densities at older ages were not available for sampling, and expected values are not listed for these categories.

The diameter distributions presented differ somewhat from those published by Clutter and Bennett in 1965. The 1965 analysis included data from 187 plots in the middle coastal plain of Georgia. Most of these plots were obtained in plantations with wide spacings, the prevailing type in the area. In contrast, 27 percent of the 478 stands included in the present analysis had from 600 to 1,100 surviving trees per acre. However, only 21 plots 20 years of age and above displayed densities greater than 400 trees per acre.

Basal area yields can be calculated from the diameter distributions (table 2). For a given density and site, basal area yield increases with age, of course, but at a declining rate as age increases. This is illustrated by the periodic annual increases for site 70:

	Trees per acre		
Age period	200	300	400
	(Square feet per acre)		
15-20	3.4	4.4	5.4
20-25	2.4	3.0	3.6
25-30	1.6	2.2	2.6

Conversely, the effects of site and density increase as age increases. For example, at age 15 with a stand of 300 trees per acre, site 70 shows a basal area of 15 more square feet than site 60; at age 25 the difference is 19 feet. Similarly, the difference in basal area between 200 and 400 trees on site 70 at age 15 is 30 feet; at age 25 the difference has increased to 46 feet.

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[3] Details of the method will be explained in a subsequent publication describing techniques involved.

DIAMETER--HEIGHT RELATIONSHIPS

Heights by diameter classes are needed to compute volume estimates. These data were established for the various age--site--density combinations from the following equation:

$$\text{Log } H = 1.64770 + 0.006258\,(S) + 0.009697\,\left(\frac{N}{100}\right) - \frac{4.75103}{A} - \frac{0.998175}{D}$$

where Log = Common logarithm

H = Total height (by specific diameter class)

A = Age in years (tree)

S = Site index (25-year basis)

D = Diameter at breast height

and N = Number of surviving trees per acre.

This regression equation was calculated from data obtained on 1,100 sample trees and accounts for 91 percent of the variation in height among the sample trees. It should be noted that the maximum heights for age 25 as estimated from this equation are generally quite close to the corresponding index heights (table 3).

MULTIPLE-PRODUCT YIELDS

For each diameter distribution, cubic-foot, board-foot, and topwood volumes per tree were calculated from the class midpoint diameters and the corresponding heights from table 3 as input to available volume equations (Bennett 1959; Collins 1965; McGee and Bennett 1959). Applying these individual tree volumes to the number of trees in each diameter class for a given age--site--density regime produced the per acre cubic- and board-foot yields shown in table 4. The number of trees available for turpentining was readily determined from the established diameter distributional patterns. Because 9.0 inches is the minimum diameter for chipping under the Naval Stores Conservation Program, one-half the trees in the 9-inch class were considered large enough for chipping. No gum yields are shown for less than 25 workable trees per acre.

BOARD-FOOT YIELDS

Little board-foot yield can be expected from plantations under age 30 on sites below 60 (table 4). For most combinations of site index and age, maximum board-foot yields are produced at the lowest stocking level--200 trees per acre. On site 80, however, yields for 300 trees per acre differ little from those obtained with 200 trees per acre at ages 25 and 30. Mean annual increment from the optimum board-foot stocking ranges from 70 board feet on site 50 to 549 board feet on site 80 at age 30. Associated with the board-foot growth values are cordwood increments ranging from 0.47 to 3.14 cords per acre per year. The cordwood growth values include trees not merchantable as sawtimber, plus topwood from the sawtimber portion of the stand.

CORDWOOD YIELDS

When all trees are considered as pulpwood material, cordwood yield, 92 cubic feet (wood plus bark) per cord, shows the usual trends in relation to age, site, and stand density (table 4). Stocking has little influence on merchantable yield at age 15 on site 50, reflecting the effect of a 5-inch merchantability limit. As the stands grow older and more trees become merchantable, yield increase per unit of stocking increase is larger. Mean annual increment culminates, in general, at age 25, with the growth rate at age 25 holding through age 30 (table 5).

With the exception of certain combinations involving closer spacings on good sites above age 20, the yields calculated from the diameter distributions agree quite well with those published by Barnes (1955). A comparison with yield estimates published by Bennett et al. (1959) in U. S. Forest Service Southeastern Forest Experiment Station Paper 107 also shows good agreement at the younger ages but indicates some discrepancy between the two tables at age 20--the highest age for which estimates were available in Station Paper 107. Where considerable divergence is present among the three estimates, the diameter distribution yields are generally intermediate in value, lying above the Barnes yields but below the Station Paper 107 figures. It should be noted that the present study includes a much larger sample of older plantations than either of the preceding studies. The Barnes study was based on 101 plots, ranging in age from 9 to 23 years, whereas the Station Paper 107 study involved data from 308 plots, including 36 plots which were 20 years of age or greater. The present analysis is based upon 478 plots of which 105 were 20 years of age and above. The distribution of these plots by age, site, and density classes is given in tables 6, 7, and 8. In spite of the large number of older plots included in the present study, information on yields from close spacings at older ages is still scanty because the 105 plots of age 20 and above included only 21 plots with more than 400 trees per acre. The lack of these older, high-density plots is not a result of mortality reduction, but reflects the fact that currently unthinned plantations installed in the study area prior to about 1945 almost invariably contain an initial spacing of 8 x 8 or wider. Hence, it is impossible to evaluate yields empirically for stands with 800 trees per acre at age 25 because no stands of this description are available for observation.

An independent evaluation of the diameter distribution technique has been carried out by Burkhart (1966), who compared measured pulpwood volumes with predicted volumes on 114 randomly located sample plots in south Georgia and north Florida. For each plot the predicted volume was obtained by entering table 4 with the appropriate age, site, and density values. Measured volume was determined by actual measurement of heights and diameters on the plot. Average actual volume for the 114 plots was 20.5 cords per acre, compared with an average estimated volume of 20.3 cords per acre.

GUM YIELDS

Bengtson and Schopmeyer (1959) presented gum yield tables for naturally occurring slash pine in which individual tree gum yields were related to tree diameter and crown ratio. Because Jones (1961) has shown there is little difference in gum yield between plantations and natural stands when tree and crown sizes are comparable, the Bengtson-Schopmeyer tables were used in the present study as a basis for estimating per acre gum production in plantations of varying ages, site indices, and densities. Application of these gum yield tables to our diameter distributions entailed the development of:

(1) A technique for predicting 4-year diameter growth on faced trees while allowing for a 25 percent reduction in normal diameter increment through loss of vigor due to chipping (Schopmeyer 1955).

(2) Methods for predicting the crown ratio of a tree as a function of its diameter and the age, site, and density of the stand in which it is grown.

The technique adopted for diameter growth projection was based on mathematical manipulation of the diameter distribution curves mentioned previously, and crown ratio predictions were obtained from an equation developed through regression analysis of data from 1,701 sample trees. Because the computations involved in the prediction of gum yield are quite involved, a comprehensive description of these techniques will not be presented here.

As with sawtimber, little gum can be produced on lands with a site index classification less than 60 (tables 4 and 9). Except in stands of 200 trees per acre, naval stores operations will not be possible on site 60 until after age 20. In general, the greatest gum yield comes from stands that produce the greatest board-foot yield. On sites 70 and below, these are stands of 300 trees per acre or less. At ages 25 and 30 on site 80, 400 trees per acre produce the greatest gum yield. Yield per tree and per crop is always the greatest, of course, from the 200-tree stand. This is a reflection of the large diameters and the high crown ratio levels associated with this density.

Gum yields shown in tables 4 and 9 are from the last 4 years of the given rotation age. Yields at age 25, for example, were produced over the 4-year period beginning with age 21.

For a given surviving stand, gum yield per tree does not increase appreciably with age (figure 1). The average yield per tree for a 200-tree stand on site 70, for example, is practically the same whether the chipping cycle is instituted at age 16 (20-year yield) or age 26 (30-year yield). As illustrated below, the number of workable trees, as well as the mean diameter of these trees, increases with age, but the mean crown ratio level drops sharply:

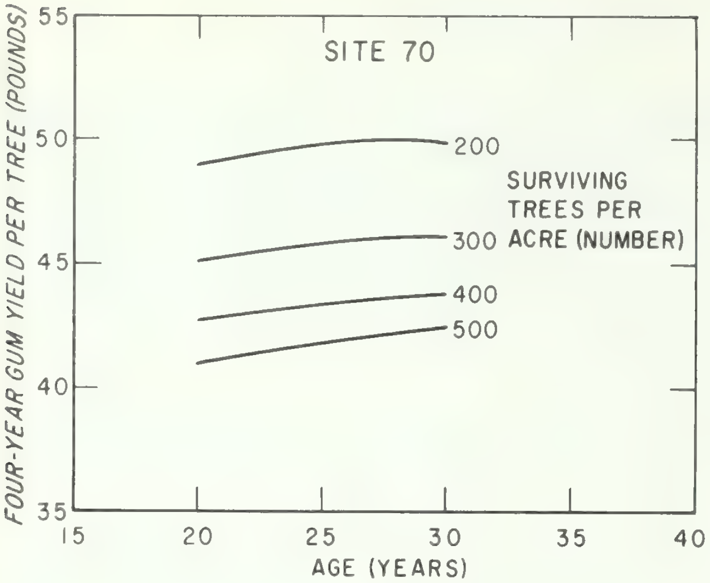

Figure 1.--Four-year gum yield per tree increases only slightly with age.

Age	Workable trees per acre	Mean d.b.h.	Mean crown ratio level	Annual gum yield	
				Per tree	Per acre
(Years)	(Number)	(Inches)	(Percent)	(Pounds)	(Barrels)
16	80	9.9	57	11.88	2.180
26	132	10.8	40	11.96	3.623

The significant drop in the average crown ratio level--from 57 to 40 percent--is responsible for the lack of an increase in gum yield per tree with an appreciable increase in diameter. The increase in yield per acre with age is the result of the increase in the number of trees being worked. It should also be noted that chipping time per tree will be reduced slightly in the older stand as a result of a decrease in average distance between faced trees. This means an individual worker would be able to chip more trees per day and per week.

DECREASE IN WOOD YIELD AS A RESULT OF TURPENTINING

Considering all trees as pulpwood, growth lost as a result of turpentining can amount to as much as a cord per acre over the 4-year chipping cycle on the best site (table 4). On site 70, cubic foot losses are generally less than 0.6 cord per acre over the 4-year period, whereas sawtimber losses range from about 50 to more than 350 board feet.

For a combination of sawtimber and pulpwood, the only significant growth loss due to turpentining occurs in the board-foot component of the multiple-product yields. Such a result is, of course, expected because most trees large enough to be faced will be of sawtimber size by the end of the rotation. However, some cubic foot loss will occur on a few faced nonsawtimber trees. On the other hand, it is possible for the nonsawtimber volume component to be increased as a result of facing because the decrease in diameter growth resulting from turpentining may prevent some 9-inch trees from growing into the 10-inch class, which is the minimum size for sawtimber. Because of these partially compensating effects, the effect of facing on nonsawtimber cubic foot volume is erratic in direction and completely insignificant in magnitude.

Considering the volume of gum produced, growth losses due to turpentining are inconsequential. At age 25 on site 70, for example, chipping a stand of 200 trees per acre over a 4-year period results in a loss of 365 board feet or 0.62 cords, but 12.6 barrels of gum are produced.

RETURNS

The per acre values at rotation age for various combinations of products have been calculated using prices of $7 per cord for pulpwood, $30 per MBF for sawtimber, and $6 per barrel for gum. These values are given in table 9 as functions of age, site, and density.

On sites 50 and 60, 200 to 400 trees per acre generally give the greatest total return when pulpwood, sawtimber, and gum are produced in combination (table 9). On these sites the combination of pulpwood and gum usually gives a greater return than that of pulpwood and sawtimber. Total gross return on sites 70 and above does not culminate in relation to number of trees per acre. This contradicts return figures (Bennett 1965) calculated from the diameter distributions published in 1965 (Clutter and Bennett). The difference in the two analyses stems from the fact that cubic yields from the present analysis are higher for the heavier stockings than those in the 1965 analysis, whereas sawtimber yields are lower. This is a reflection of the expanded sample in the close spacings and the larger sample, in general, in the second analysis.

The returns in table 9 are based on what were considered representative product prices for the region covered by the sample data. In some areas, sawtimber and pulpwood prices are already somewhat higher than the values used; in other areas the price differential between the two products is considerably different from that indicated. These problems cannot be generally resolved without calculating returns from a wide range of product prices, including expected future increases, which is beyond the practical scope of this paper. Readers who may be interested in gross returns for a specific combination of prices, however, will find it a relatively simple matter to prepare their own versions of table 10 by applying their price data to the yield estimates given in table 4.

Because net return depends upon a variety of decisions that must be made by the landowner or forest manager, no attempt has been made to calculate these data. Illustrations of the net return to expect under various management objectives will be the subject of a separate paper.

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Table 1.--Diameter distributions by age, site, and stand density schedules

AGE 15

Trees (number)	Site index[1]	Diameter class (Inches)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Number of trees per acre														
200	50				7	24	44	57	49	19						
	60				2	12	29	46	53	43	15					
	70					6	19	35	47	49	35	9				
	80					3	12	26	40	47	44	25	3			
300	50			6	29	63	86	79	36	1						
	60			1	13	39	67	81	69	29	1					
	70				6	24	49	71	76	56	18					
	80				2	14	36	58	72	68	42	8				
400	50		1	21	64	106	116	77	15							
	60			7	35	75	105	103	64	11						
	70			2	18	51	85	103	89	47	5					
	80			1	9	34	67	92	96	72	28	1				
500	50		6	45	105	145	130	64	5							
	60		1	19	64	114	136	112	51	3						
	70			7	38	84	120	126	91	33	1					
	80			2	22	60	100	122	111	67	16					
600	50		17	77	147	174	134	49	2							
	60		4	37	98	150	159	113	38	1						
	70		1	17	63	119	151	140	87	22						
	80			7	40	90	133	145	117	59	9					
700	50	1	34	112	185	196	132	39	1							
	60		10	61	134	183	174	109	29							
	70		2	31	92	153	177	149	80	16						
	80			15	62	122	163	163	119	51	5					
800	50	4	55	150	219	212	128	32								
	60		20	88	169	211	184	104	24							
	70		6	49	123	184	198	153	75	12						
	80		2	26	87	153	189	176	118	45	4					

AGE 20

Trees (number)	Site index[1]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
200	50				4	13	28	42	48	43	21	1				
	60				1	7	17	30	41	45	39	19	1			
	70					3	11	22	33	41	43	33	14			
	80					1	7	16	26	36	41	38	27	8		
300	50			3	17	39	62	75	67	35	2					
	60			1	7	23	44	62	70	60	31	2				
	70				3	14	30	49	63	65	52	23	1			
	80				1	8	21	38	54	63	59	42	14			
400	50		1	11	38	73	98	98	66	15						
	60			4	20	47	76	93	88	58	14					
	70			1	10	31	57	80	89	78	46	8				
	80				5	20	42	66	82	84	66	32	3			
500	50		3	26	68	109	128	109	53	4						
	60		1	10	39	77	109	118	96	46	4					
	70			4	22	53	86	109	109	81	34	2				
	80			1	12	37	68	94	107	97	64	20				
600	50		10	47	101	144	150	109	38	1						
	60		2	22	63	109	139	136	95	33	1					
	70			10	38	80	117	135	121	77	22					
	80			4	23	58	95	122	127	103	57	11				
700	50	1	20	72	136	175	166	104	26							
	60		5	37	90	141	166	148	90	23						
	70		1	18	58	108	147	156	128	70	14					
	80			8	38	81	124	148	142	105	48	6				

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[1] 25-year basis.

Table 1.--Diameter distributions by age, site, and stand density schedules (continued)

AGE 25

Trees (number)	Site index[1]	Diameter class (Inches)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Number of trees per acre														
200	50				3	10	21	33	43	44	34	12				
	60				1	5	13	23	34	41	40	31	12			
	70					2	8	17	26	35	39	37	27	9		
	80					1	5	12	20	29	36	38	33	21	5	
300	50			2	12	29	50	65	69	53	20					
	60				5	17	34	51	63	63	48	19				
	70				2	10	23	39	53	60	58	41	14			
	80				1	6	16	29	44	54	58	51	33	8		
400	50			8	29	57	82	94	82	44	4					
	60			3	14	36	61	81	87	74	40	4				
	70			1	7	23	44	65	80	81	65	32	2			
	80				4	14	32	52	70	79	74	54	21			
500	50		2	19	52	89	115	115	82	26						
	60			8	29	60	90	109	105	74	25					
	70			3	16	40	69	94	104	94	62	18				
	80			1	9	27	53	78	95	98	82	48	9			
600	50		7	35	79	122	143	127	74	13						
	60		1	16	47	87	121	133	115	67	13					
	70			7	28	62	96	121	124	100	54	8				
	80			3	17	44	76	104	119	113	83	38	3			

AGE 30

Trees (number)	Site index[1]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
200	50				2	8	18	29	38	43	38	22	2			
	60				1	4	11	20	29	37	39	35	21	3		
	70					2	7	14	22	31	36	37	31	18	2	
	80					1	4	10	17	25	32	36	34	27	13	
300	50			2	10	24	43	58	66	59	34	4				
	60				4	14	28	44	57	62	54	32	5			
	70				2	8	19	33	46	56	58	48	27	3		
	80				1	4	13	25	38	49	55	53	41	20	1	
400	50			7	23	48	73	88	86	59	16					
	60			2	12	29	52	72	83	78	55	17				
	70				6	19	37	57	72	79	71	47	12			
	80				3	12	27	45	62	73	74	62	36	6		
500	50		2	15	43	76	104	113	95	48	4					
	60			6	23	50	79	100	105	86	46	5				
	70			2	13	33	59	83	98	97	75	37	3			
	80			1	7	22	44	68	86	95	88	63	25	1		

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[1] 25-year basis.

Table 2.--Basal area yields calculated from diameter distributions

Age (years)	Site index[1]	Trees per acre						
		200	300	400	500	600	700	800
		Square feet per acre						
15	50	53	63	70	76	81	86	90
	60	66	79	89	98	106	113	121
	70	77	94	107	119	130	140	150
	80	87	108	124	139	153	165	[2]177
20	50	67	79	89	97	103	109	
	60	81	98	112	124	134	143	
	70	94	116	134	149	162	174	
	80	106	133	154	173	189	[2]204	
25	50	75	90	102	111	119		
	60	91	112	128	141	153		
	70	106	131	152	169	185		
	80	119	150	174	196	[2]215		
30	50	82	99	112	122			
	60	98	121	139	154			
	70	114	142	165	184			
	80	128	162	189	212			

[1] 25-year basis.

[2] Values below this point are omitted because they are well beyond the range of the basic data.

Table 3.--Heights by diameter classes for various age, site, and stand density combinations

AGE 15

Trees per acre (number)	Site index[1]	Diameter class (Inches)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Height in feet														
200	50				26	29	31	33	35	36						
	60				30	34	36	38	40	41	42					
	70					39	42	44	46	48	49	50				
	80					45	48	51	53	55	56	58	59			
300	50			22	27	30	32	34	35	36						
	60			25	31	34	37	39	41	42	43					
	70				35	40	43	45	47	49	50					
	80				41	46	49	52	54	56	58	59				
400	50		15	22	27	30	33	35	36							
	60			26	31	35	38	40	42	43						
	70			30	36	41	44	46	48	50	51					
	80			34	42	47	51	53	56	57	59	60				
500	50		16	23	28	31	34	35	37							
	60		18	26	32	36	39	41	43	44						
	70			31	37	41	45	47	49	51	52					
	80			35	43	48	52	55	57	59	60					
600	50		16	23	28	32	34	36	38							
	60		18	27	33	37	40	42	44	45						
	70		21	31	38	42	46	48	50	52						
	80			36	44	49	53	56	58	60	62					
700	50	5	16	24	29	33	35	37	39							
	60		19	28	33	38	41	43	45							
	70		22	32	39	43	47	49	52	53						
	80			37	45	50	54	57	60	61	63					
800	50	5	17	24	30	33	36	38	40							
	60		19	28	34	38	41	44	46							
	70		22	33	40	44	48	51	53	54						
	80		26	38	46	51	55	58	61	63	64					

AGE 20

Trees per acre (number)	Site index[1]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
200	50				31	35	38	40	41	43	44	45				
	60				36	40	44	46	48	49	51	52	53			
	70					47	50	53	55	57	59	60	61			
	80					54	58	61	64	66	68	69	70	71		
300	50			26	32	36	39	41	42	44	45					
	60			30	37	41	44	47	49	51	52	53				
	70				42	48	51	54	57	58	60	61	62			
	80				49	55	59	63	65	67	69	71	72			
400	50		18	27	33	36	39	42	43	45						
	60			31	38	42	46	48	50	52	53					
	70			36	43	49	53	56	58	60	61	63				
	80				50	56	61	64	67	69	71	72	74			
500	50		19	27	33	37	40	43	44	46						
	60		22	32	38	43	47	49	51	53	54					
	70			37	44	50	54	57	59	61	63	64				
	80			42	51	57	62	66	68	71	72	74				
600	50		19	28	34	38	41	44	45	47						
	60		22	32	39	44	48	50	52	54	55					
	70			37	45	51	55	58	60	62	64					
	80			43	52	59	63	67	70	72	74	76				
700	50	6	20	29	35	39	42	44	46	48						
	60		23	33	40	45	49	51	54	55						
	70		26	38	46	52	56	59	62	64	66					
	80			44	54	60	65	69	71	74	76	77				

[1] 25-year basis.

Table 3.--Heights by diameter classes for various age, site, and stand density combinations (continued)

AGE 25

Trees per acre (number)	Site index[1]	Diameter class (Inches)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Height in feet														
200	50				35	39	42	44	46	48	49	50				
	60				40	45	49	51	53	55	57	58	59			
	70					52	56	59	62	64	65	67	68	69		
	80					60	65	68	71	74	75	77	78	80	81	
300	50			29	35	40	43	45	47	49	50					
	60				41	46	50	52	55	56	58	59				
	70				47	53	57	61	63	65	67	68	69			
	80				55	61	66	70	73	75	77	79	80	81		
400	50			30	36	41	44	46	48	50	51					
	60			35	42	47	51	54	56	58	59	60				
	70			40	48	54	59	62	65	67	68	70	71			
	80				56	63	68	72	75	77	79	81	82			
500	50		21	31	37	42	45	47	49	51						
	60			35	43	48	52	55	57	59	61					
	70			41	50	56	60	63	66	68	70	71				
	80			47	57	64	69	73	76	79	81	82	84			
600	50		21	31	38	43	46	49	51	52						
	60		25	36	44	49	53	56	58	60	62					
	70			42	51	57	61	65	67	70	71	73				
	80			48	58	66	71	75	78	80	83	84	86			

AGE 30

Trees per acre (number)	Site index[1]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
200	50				37	42	45	48	50	51	53	54	55			
	60				43	48	52	55	57	59	61	62	63	64		
	70					56	60	64	66	69	70	72	73	74	75	
	80					65	70	74	77	79	81	83	84	86	87	
300	50			32	38	43	46	49	51	53	54	55				
	60				44	49	53	56	59	61	62	64	65			
	70				51	57	62	65	68	70	72	73	75	76		
	80				59	66	71	75	78	81	83	85	86	88	89	
400	50			32	39	44	47	50	52	54	55					
	60			37	45	51	55	58	60	62	64	65				
	70				52	58	63	67	69	72	74	75	76			
	80				60	67	73	77	80	83	85	87	88	90		
500	50		22	33	40	45	48	51	53	55	56					
	60			38	46	52	56	59	61	63	65	66				
	70			44	53	60	64	68	71	73	75	77	78			
	80			51	62	69	74	79	82	85	87	89	90	92		

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[1] 25-year basis.

Table 4.--Per acre sawtimber, pulpwood, and gum yields

SITE INDEX 50[1]

Age (years)	Trees per acre	Wood yields without facing			Wood yields with facing			Gum yield per acre 4-year total
		All trees as pulpwood	Multiple product		All trees as pulpwood	Multiple product		
			Sawtimber	Pulpwood		Sawtimber	Pulpwood	
	Number	Cords	Bd. ft.	Cords	Cords	Bd. ft.	Cords	Barrels
15	200	7.3	0	7.3	7.3	0	7.3	0
	300	7.7	0	7.7	7.7	0	7.7	0
	400	7.7	0	7.7	7.7	0	7.7	0
	500	7.6	0	7.6	7.6	0	7.6	0
	600	7.6	0	7.6	7.6	0	7.6	0
	700	7.5	0	7.5	7.5	0	7.5	0
	800	7.6	0	7.6	7.6	0	7.6	0
20	200	12.6	0	12.6	12.6	0	12.6	0
	300	14.1	0	14.1	14.1	0	14.1	0
	400	14.9	0	14.9	14.9	0	14.9	0
	500	15.4	0	15.4	15.4	0	15.4	0
	600	15.7	0	15.7	15.7	0	15.7	0
	700	16.0	0	16.0	16.0	0	16.0	0
25	200	16.9	1,197	13.1	16.7	1,158	13.0	4.890
	300	19.3	0	19.3	19.3	0	19.3	2.286
	400	20.9	0	20.9	20.9	0	20.9	0
	500	22.1	0	22.1	22.1	0	22.1	0
	600	22.9	0	22.9	22.9	0	22.9	0
30	200	20.3	2,107	14.2	20.1	2,058	14.1	7.042
	300	23.6	1,117	20.4	23.5	1,095	20.3	4.606
	400	25.9	0	25.9	25.8	0	25.8	2.544
	500	27.5	0	27.5	27.5	0	27.5	0
SITE INDEX 60[1]								
15	200	11.8	0	11.8	11.8	0	11.8	0
	300	13.2	0	13.2	13.2	0	13.2	0
	400	14.2	0	14.2	14.2	0	14.2	0
	500	14.9	0	14.9	14.9	0	14.9	0
	600	15.5	0	15.5	15.5	0	15.5	0
	700	16.1	0	16.1	16.1	0	16.1	0
	800	16.7	0	16.7	16.7	0	16.7	0
20	200	19.2	1,737	13.9	18.9	1,611	14.0	5.041
	300	22.5	0	22.5	22.5	0	22.5	0
	400	24.9	0	24.9	24.9	0	24.9	0
	500	26.8	0	26.8	26.8	0	26.8	0
	600	28.4	0	28.4	28.4	0	28.4	0
	700	29.8	0	29.8	29.8	0	29.8	0
25	200	25.1	3,627	15.3	24.7	3,510	15.2	9.096
	300	30.0	2,519	23.3	29.7	2,446	23.2	6.909
	400	33.7	1,559	29.6	33.5	1,527	29.5	4.636
	500	36.7	0	36.7	36.5	0	36.5	2.970
	600	39.2	0	39.2	39.2	0	39.2	0
30	200	29.8	5,360	16.0	29.5	5,240	16.0	11.184
	300	36.0	4,272	25.2	35.7	4,181	25.2	10.045
	400	40.8	3,095	33.2	40.5	3,034	33.1	8.058
	500	44.7	2,088	39.7	44.5	2,051	39.6	6.122

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[1] 25-year basis.

Table 4.--Per acre sawtimber, pulpwood, and gum yields (continued)

SITE INDEX 70[1]

Age (years)	Trees per acre	Wood yields without facing			Wood yields with facing			Gum yield per acre 4-year total
		All trees as pulpwood	Multiple product		All trees as pulpwood	Multiple product		
			Sawtimber	Pulpwood		Sawtimber	Pulpwood	
	Number	Cords	Bd. ft.	Cords	Cords	Bd. ft.	Cords	Barrels
15	200	17.2	1,092	13.7	17.1	0	13.7	0
	300	20.1	0	20.1	20.1	0	20.1	0
	400	22.4	0	22.4	22.4	0	22.4	0
	500	24.2	0	24.2	24.2	0	24.2	0
	600	25.9	0	25.9	25.9	0	25.9	0
	700	27.5	0	27.5	27.5	0	27.5	0
	800	29.1	0	29.1	29.1	0	29.1	0
20	200	27.1	4,203	16.0	26.5	3,945	16.1	8.721
	300	32.7	3,085	24.7	32.3	2,894	24.8	6.158
	400	37.2	2,087	31.9	36.9	1,906	32.1	3.933
	500	40.9	1,342	37.6	40.7	1,267	37.6	2.518
	600	44.3	0	44.3	44.3	0	44.3	0
	700	47.4	0	47.4	47.4	0	47.4	0
25	200	35.0	7,297	17.0	34.4	6,932	17.3	12.639
	300	42.9	6,380	27.5	42.3	6,201	27.4	11.974
	400	49.2	5,170	37.0	48.7	5,038	36.9	9.960
	500	54.7	4,036	45.3	54.2	3,943	45.2	8.062
	600	59.5	3,085	52.5	59.1	3,031	52.3	6.436
30	200	41.3	9,924	17.5	40.8	9,718	17.6	14.493
	300	51.1	9,406	29.0	50.5	9,203	29.0	15.029
	400	59.0	8,287	40.0	58.4	8,118	39.9	14.129
	500	65.7	6,999	50.1	65.3	6,875	50.0	12.642
SITE INDEX 80[1]								
15	200	23.7	2,778	16.1	23.7	2,778	16.1	0
	300	28.5	1,703	24.0	28.5	1,703	24.0	0
	400	32.4	0	32.4	32.4	0	32.4	0
	500	35.8	0	35.8	35.8	0	35.8	0
	600	38.9	0	38.9	38.9	0	38.9	0
	700	41.9	0	41.9	41.9	0	41.9	0
	800	44.9	0	44.9	44.9	0	44.9	0
20	200	36.7	7,745	17.8	35.7	7,330	18.0	11.916
	300	45.1	6,820	29.0	44.2	6,451	29.1	10.345
	400	52.1	5,614	39.1	51.4	5,291	39.3	8.195
	500	58.2	4,504	48.0	57.7	4,085	48.6	6.340
	600	63.8	3,602	55.8	63.4	1,823	59.2	4.984
	700	69.1	2,905	62.7	68.7	1,399	65.5	4.054
25	200	47.0	12,167	18.6	46.1	11,555	19.2	15.509
	300	58.5	12,008	31.1	57.5	11,432	31.6	16.187
	400	68.1	11,050	43.5	67.1	10,747	43.4	15.358
	500	76.6	9,853	55.1	75.7	9,602	54.9	13.956
	600	84.3	8,630	65.8	83.5	8,434	65.6	12.444
30	200	55.1	15,798	18.9	54.4	15,509	19.0	17.090
	300	69.2	16,460	32.3	68.3	16,144	32.4	19.201
	400	81.0	16,002	46.0	80.1	15,701	45.9	19.626
	500	91.3	14,983	59.3	90.5	14,718	59.2	19.142

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[1] 25-year basis.

Table 5.--Mean annual cordwood increment by age, site, and surviving trees per acre

Site index[1]	Age	Trees per acre						
		200	300	400	500	600	700	800
	Years	Cords per acre per year						
50	15	0.49	0.51	0.51	0.51	0.50	0.50	0.51
	20	0.63	0.70	0.74	0.77	0.79	0.80	
	25	0.67	0.77	0.84	0.88	0.92		
	30	0.67	0.79	0.86	0.91			
60	15	0.79	0.88	0.95	0.99	1.03	1.07	1.11
	20	0.96	1.12	1.24	1.34	1.41	1.49	
	25	1.00	1.20	1.35	1.47	1.57		
	30	0.99	1.20	1.36	1.49			
70	15	1.15	1.34	1.49	1.62	1.73	1.83	1.94
	20	1.36	1.64	1.86	2.05	2.21	2.37	
	25	1.40	1.72	1.96	2.19	2.38		
	30	1.38	1.70	1.97	2.19			
80	15	1.58	1.90	2.16	2.39	2.60	2.80	2.99
	20	1.83	2.26	2.61	2.91	3.19	3.45	
	25	1.88	2.34	2.72	3.06	3.37		
	30	1.84	2.30	2.70	3.04			

[1] 25-year basis.

Table 6.--Distribution of sample plots by age and site index

Age (years)	Site index[1]						
	≤35	40	50	60	70	≥76	Total
≤10	2	3	2	22	19	4	52
12	0	3	6	33	54	22	118
15	1	5	7	37	34	6	90
18	1	1	4	38	63	6	113
21	0	2	6	25	26	10	69
24	0	2	4	8	9	0	23
27	0	0	2	5	2	0	9
30	0	0	0	1	0	0	1
≥32	0	0	0	3	0	0	3
Total	4	16	31	172	207	48	478

[1] 25-year basis.

Table 7.--Distribution of sample plots by age and density

Age (years)	Density										
	≤155	200	300	400	500	600	700	800	900	1,000	≥1,056	Total
≤10	1	3	7	6	7	6	8	10	3	1	0	52
12	3	3	8	17	23	30	26	5	2	1	0	118
15	0	11	18	13	29	11	4	2	2	0	0	90
18	9	27	20	22	23	6	4	1	1	0	0	113
21	4	17	20	12	8	4	1	0	0	2	1	69
24	4	9	4	1	4	0	1	0	0	0	0	23
27	0	8	1	0	0	0	0	0	0	0	0	9
30	0	1	0	0	0	0	0	0	0	0	0	1
≥32	0	3	0	0	0	0	0	0	0	0	0	3
Total	21	82	78	71	94	57	44	18	8	4	1	478

Table 8.--Distribution of sample plots by density and site index

Site index[1]	Density										
	≤155	200	300	400	500	600	700	800	900	1,000	≥1,056	Total
≤35	0	0	1	0	2	0	0	1	0	0	0	4
40	1	1	9	2	1	1	0	1	0	0	0	16
50	0	5	5	7	8	1	2	1	2	0	0	31
60	7	38	28	26	31	16	11	7	4	3	1	172
70	12	34	25	32	42	31	22	6	2	1	0	207
≥76	1	4	10	4	10	8	9	2	0	0	0	48
Total	21	82	78	71	94	57	44	18	8	4	1	478

[1] 25-year basis.

Table 9.--Gum production data

SITE INDEX 50[1]

Age (years)	Trees per acre	Trees per acre 9.0 inches and above	Gum yield				
			Per acre		Per tree		Per crop (10,000 faces)
			Annual	4-year total	Annual	4-year total	Annual
	Number	Number	- - Barrels - -		- - Pounds - -		Barrels
15	200	0	0	0	0	0	0
	300	0	0	0	0	0	0
	400	0	0	0	0	0	0
	500	0	0	0	0	0	0
	600	0	0	0	0	0	0
	700	0	0	0	0	0	0
	800	0	0	0	0	0	0
20	200	16	0	0	0	0	0
	300	3	0	0	0	0	0
	400	0	0	0	0	0	0
	500	0	0	0	0	0	0
	600	0	0	0	0	0	0
	700	0	0	0	0	0	0
25	200	49	1.222	4.890	10.85	43.41	249
	300	25	0.571	2.286	9.88	39.54	227
	400	11	0	0	0	0	0
	500	4	0	0	0	0	0
	600	1	0	0	0	0	0
30	200	72	1.761	7.042	10.70	42.81	246
	300	51	1.152	4.606	9.82	39.26	226
	400	30	0.636	2.544	9.28	37.11	213
	500	16	0	0	0	0	0
SITE INDEX 60[1]							
15	200	0	0	0	0	0	0
	300	0	0	0	0	0	0
	400	0	0	0	0	0	0
	500	0	0	0	0	0	0
	600	0	0	0	0	0	0
	700	0	0	0	0	0	0
	800	0	0	0	0	0	0
20	200	48	1.260	5.041	11.46	45.83	263
	300	24	0	0	0	0	0
	400	11	0	0	0	0	0
	500	5	0	0	0	0	0
	600	2	0	0	0	0	0
	700	1	0	0	0	0	0
25	200	87	2.274	9.096	11.42	45.69	263
	300	72	1.727	6.909	10.49	41.95	241
	400	51	1.159	4.636	9.89	39.57	227
	500	34	0.742	2.970	9.48	37.92	218
	600	23	0	0	0	0	0
30	200	107	2.796	11.184	11.36	45.46	261
	300	104	2.511	10.045	10.47	41.88	241
	400	88	2.014	8.058	9.93	39.74	228
	500	69	1.530	6.122	9.62	38.47	221

[1] 25-year basis.

Table 9.--Gum production data (continued)

SITE INDEX 70[1]

Age (years)	Trees per acre	Trees per acre 9.0 inches and above	Gum yield				
			Per acre		Per tree		Per crop (10,000 faces)
			Annual	4-year total	Annual	4-year total	Annual
	Number	Number	- - Barrels - -		- - Pounds - -		Barrels
15	200	8	0	0	0	0	0
	300	0	0	0	0	0	0
	400	0	0	0	0	0	0
	500	0	0	0	0	0	0
	600	0	0	0	0	0	0
	700	0	0	0	0	0	0
	800	0	0	0	0	0	0
20	200	80	2.180	8.721	11.88	47.51	273
	300	61	1.539	6.158	10.92	43.69	251
	400	42	0.983	3.933	10.28	41.14	236
	500	28	0.630	2.518	9.88	39.52	227
	600	19	0	0	0	0	0
	700	14	0	0	0	0	0
25	200	115	3.160	12.639	11.95	47.78	275
	300	117	2.949	11.974	10.97	43.87	252
	400	104	2.490	9.960	10.38	41.53	239
	500	88	2.015	8.062	10.00	40.01	230
	600	72	1.609	6.436	9.72	38.89	224
30	200	132	3.623	14.493	11.96	47.83	275
	300	148	3.757	15.029	11.03	44.12	254
	400	146	3.532	14.129	10.49	41.95	241
	500	136	3.160	12.642	10.15	40.58	233
			SITE INDEX 80[1]				
15	200	24	0	0	0	0	0
	300	8	0	0	0	0	0
	400	2	0	0	0	0	0
	500	1	0	0	0	0	0
	600	0	0	0	0	0	0
	700	0	0	0	0	0	0
	800	0	0	0	0	0	0
20	200	106	2.979	11.916	12.24	48.95	281
	300	100	2.586	10.345	11.26	45.06	259
	400	84	2.049	8.195	10.66	42.66	245
	500	67	1.585	6.340	10.23	40.93	235
	600	55	1.246	4.984	9.94	39.74	228
	700	45	1.013	4.054	9.73	38.94	224
25	200	136	3.877	15.509	12.43	49.73	286
	300	154	4.047	16.187	11.43	45.72	263
	400	154	3.839	15.358	10.83	43.31	249
	500	145	3.489	13.956	10.43	41.74	240
	600	133	3.111	12.444	10.16	40.64	234
30	200	149	4.273	17.090	12.47	49.88	287
	300	181	4.800	19.201	11.51	46.03	265
	400	195	4.906	19.626	10.95	43.78	252
	500	196	4.786	19.142	10.60	42.41	244

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[1] 25-year basis.

Table 10.--Gross per acre returns for various product combinations

SITE INDEX 50[1]

Age (years)	Trees per acre	All trees as pulpwood	Pulpwood and gum	Pulpwood and sawtimber	Pulpwood, sawtimber, and gum
	Number	Dollars[2]			
15	200	51.38	--	--	--
	300	53.62	--	--	--
	400	53.90	--	--	--
	500	53.34	--	--	--
	600	52.92	--	--	--
	700	52.78	--	--	--
	800	53.13	--	--	--
20	200	88.20	--	--	--
	300	98.42	--	--	--
	400	104.37	--	--	--
	500	107.87	--	--	--
	600	110.25	--	--	--
	700	112.21	--	--	--
25	200	118.09	146.24	127.40	155.15
	300	135.38	148.54	--	--
	400	146.65	--	--	--
	500	154.49	--	--	--
	600	160.30	--	--	--
30	200	141.89	182.88	162.33	202.83
	300	165.20	192.00	176.31	202.94
	400	181.30	196.00	--	--
	500	192.78	--	--	--
SITE INDEX 60[1]					
15	200	82.53	--	--	--
	300	92.75	--	--	--
	400	99.47	--	--	--
	500	104.30	--	--	--
	600	108.57	--	--	--
	700	112.70	--	--	--
	800	117.04	--	--	--
20	200	134.26	162.34	149.62	176.51
	300	157.36	--	--	--
	400	174.30	--	--	--
	500	187.46	--	--	--
	600	198.66	--	--	--
	700	208.67	--	--	--
25	200	175.84	227.83	215.84	266.63
	300	209.93	249.21	238.46	277.09
	400	235.76	262.11	254.04	280.13
	500	256.62	273.60	--	--
	600	274.47	--	--	--
30	200	208.88	273.53	273.15	336.51
	300	252.21	310.31	304.84	361.96
	400	285.60	332.20	324.97	371.00
	500	312.90	348.09	340.33	375.18

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[1] 25-year basis.

[2] Pulpwood stumpage at $7.00 per cord.
Sawtimber stumpage at $30.00 per MBF.
Gum at $6.00 per barrel.

Table 10.--Gross per acre returns for various product combinations (continued)

SITE INDEX 70[1]

Age (years)	Trees per acre	All trees as pulpwood	Pulpwood and gum	Pulpwood and sawtimber	Pulpwood, sawtimber, and gum
	Number	Dollars[2]			
15	200	120.33	--	128.59	--
	300	140.98	--	--	--
	400	156.66	--	--	--
	500	169.68	--	--	--
	600	181.44	--	--	--
	700	192.64	--	--	--
	800	203.77	--	--	--
20	200	189.84	237.83	238.23	283.59
	300	229.18	262.77	265.73	297.51
	400	260.26	281.76	285.84	305.55
	500	286.51	300.22	303.46	316.53
	600	309.89	--	--	--
	700	331.52	--	--	--
25	200	245.35	316.84	337.91	405.17
	300	300.44	368.15	383.69	449.53
	400	344.68	400.87	414.10	468.99
	500	382.62	427.98	438.32	482.78
	600	416.29	452.67	459.98	495.86
30	200	289.38	372.63	420.57	501.42
	300	357.42	443.53	485.18	569.12
	400	412.86	493.78	528.54	607.75
	500	460.25	532.88	560.53	631.82
SITE INDEX 80[1]					
15	200	165.83	--	196.18	--
	300	199.71	--	218.95	--
	400	226.87	--	--	--
	500	250.74	--	--	--
	600	272.65	--	--	--
	700	293.65	--	--	--
	800	314.30	--	--	--
20	200	256.69	321.61	357.30	417.75
	300	316.05	371.82	407.32	459.37
	400	364.84	408.69	442.19	482.93
	500	407.68	441.73	471.33	500.58
	600	446.81	473.63	498.87	498.92
	700	483.49	505.36	526.26	524.72
25	200	328.79	415.61	495.00	574.24
	300	409.64	499.83	578.29	661.49
	400	476.77	562.13	636.00	718.08
	500	536.06	613.50	681.43	756.24
	600	589.82	659.02	719.78	787.02
30	200	385.77	483.34	606.52	700.67
	300	484.19	593.59	720.25	826.26
	400	566.79	678.53	801.99	910.44
	500	639.45	748.35	864.59	970.72

[1] 25-year basis.

[2] Pulpwood stumpage at $7.00 per cord.
Sawtimber stumpage at $30.00 per MBF.
Gum at $6.00 per barrel.

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Fuel Consumption and Fire Behavior of Hazard Reduction Burns

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Fuel Consumption and Fire Behavior of Hazard Reduction Burns

by

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Prescribed burning has been used by many forest managers in the Southern Coastal Plains as a tool for fire hazard reduction. The general weather requirements for this type of burning have been recognized,[1] but the exact results of prescription burns applied under specific environmental conditions are not known. Forest managers must be able to predict how the environment will influence fuel consumption, heat release, and rate of spread if the fires are to meet the objectives of the prescription.

The purpose of this study was to measure fuel consumption and fire behavior of hazard reduction burns under a variety of environmental conditions.

MATERIALS AND METHODS

Prescribed burns were conducted on the Waycross State Forest in the Coastal Plain of Georgia. The timber type of the area was slash-longleaf pine with a typical understory of palmetto-gallberry. This understory had not been burned for more than 10 years. The stand averaged 50 feet in height with a basal area of 53 square feet per acre. The dry weight of the litter ranged from 4.5 to 16 tons per acre, and the dry weight of the vegetative fuel in the understory ranged from 2.5 to 3.5 tons per acre.

The plots were 2.5 to 3.5 chains square, separated by plowed firelines. Individual plots were burned over a 3-year period--in March 1959, February and March 1960, and January and February 1961. Backfires and head fires were tested in 1959 and 1960 and backfires only in 1961. Night burns were made in 1959 but not in 1960 and 1961.

Each plot was documented with respect to weather conditions at the time of burning, fuel conditions before and after burning, and the characteristics of the fire itself. Data on fuel weight and moisture content of the forest floor were obtained from square-foot samples of upper or

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[1] Dixon, Merlin J. A guide to fire by prescription. U. S. Dep. Agr., Forest Serv., South. Reg., 32 pp. 1965.

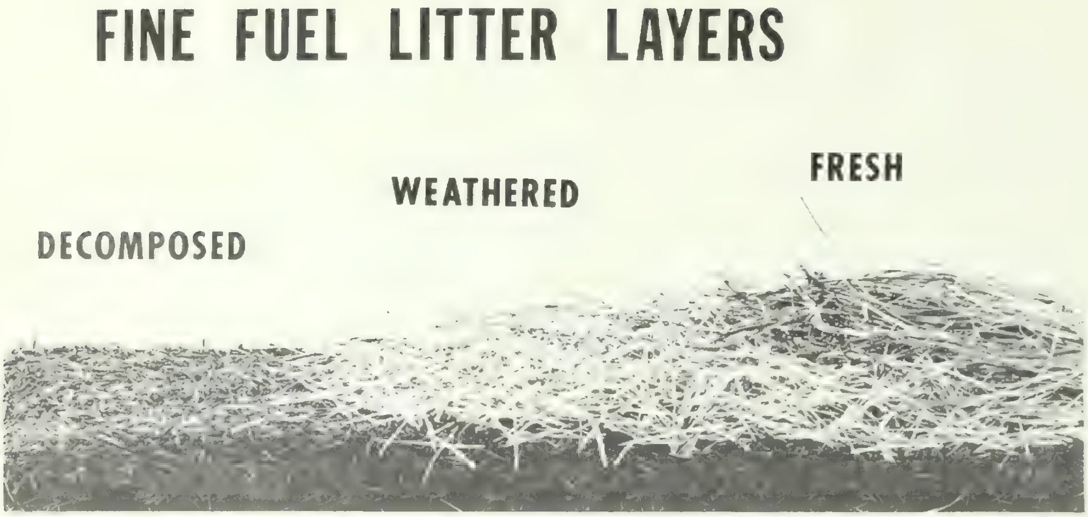

Figure 1.--Model of a forest litter bed showing layers sampled for moisture content and weight.

fresh needle litter, middle or weathered litter, and lower or decomposed litter (fig. 1). Weight and moisture content of live vegetative fuel were measured on 1/4-milacre samples for each fire.

Percentages of fuel reduction were calculated from weight measurements taken before and after burning (fig. 2). Fuel energy was calculated for each litter layer by first multiplying the weight loss of each layer by its low caloric value.[2] This gross value was then corrected for estimated heat losses due to radiation, incomplete combustion, and fuel moisture content. The resulting value was an estimate of the available fuel energy of the litter in B.t.u. per square foot. Rate of fire spread times available fuel energy gave the value of fire intensity.

An analysis of variance was made of the percentages of fuel reduction; multiple regression analyses were made to relate fuel and environmental variables with litter reduction, available fuel energy, and rate of spread.

RESULTS AND DISCUSSION

Total fuel reduction based on 16 test burns was found to be very similar for backfires and head fires, averaging 56 percent and 55 percent, respectively. Backfires, however, consumed more litter fuel (58 vs. 49 percent) and less vegetative fuel (53 vs. 61 percent) than did head fires. Backfires spread slowly and burn deeper into the litter layers, whereas head fires spread rapidly and often burn only the upper litter layer. This reaction has also occurred in laboratory test fires.[3]

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[2] Hough, W. A. Caloric value of some common forest fuels of the southeastern United States. 8 pp. 1967. (Final report on file at Southern Forest Fire Laboratory, Macon, Ga.)

[3] Beaufait, William R. Characteristics of backfires and headfires in a pine needle fuel bed. Intermountain Forest and Range Exp. Sta., U. S. Forest Serv. Res. Note INT-39, 7 pp. 1965.

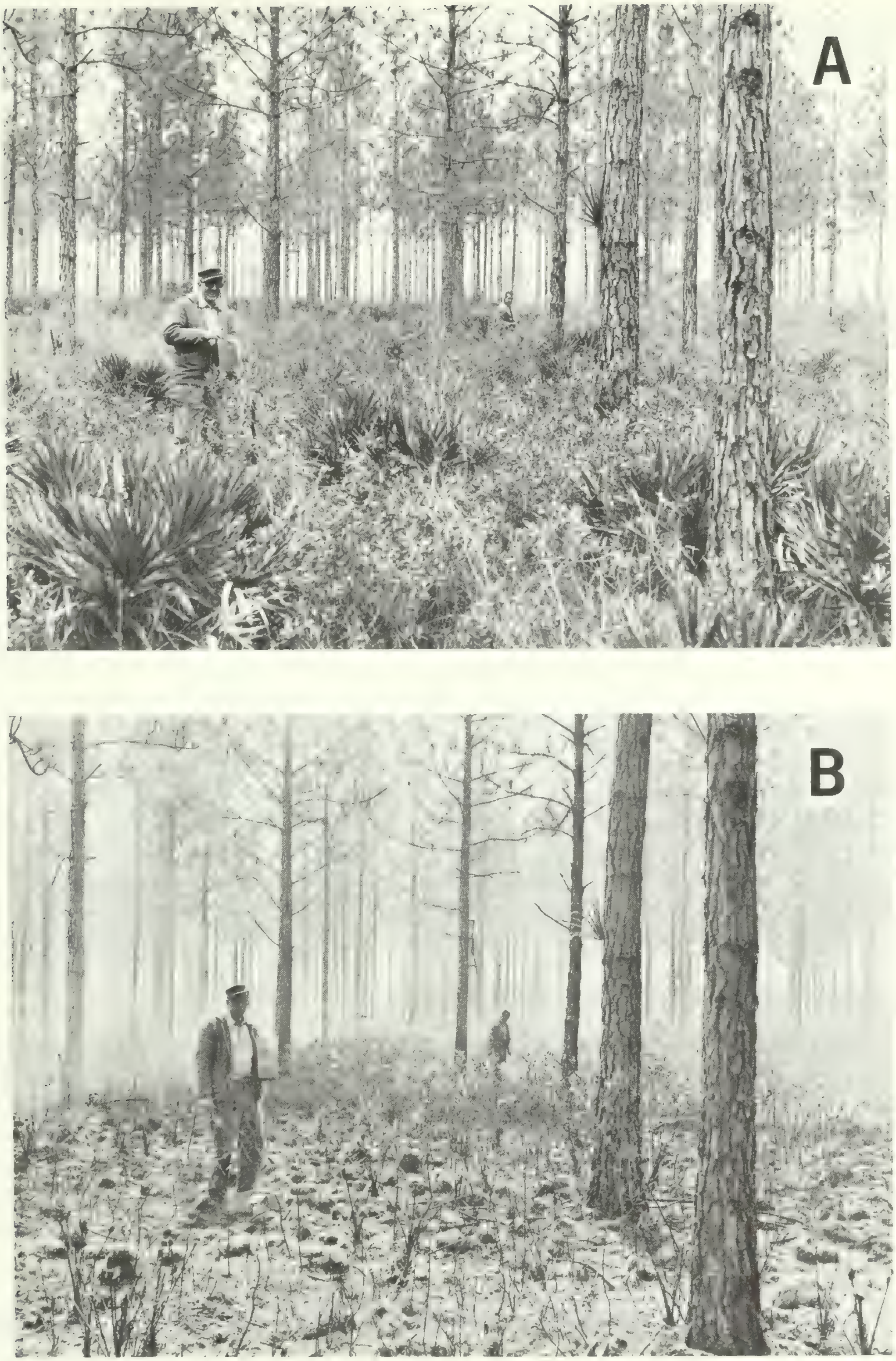

Figure 2. --Fuel samples were collected on the same plot both (A) before and (B) after a hazard reduction burn to determine their loss in weight as a result of the fire.

Because the low flames of a backfire lean away from unburned fuel, little preheating of standing vegetation occurs and consumption rates in the aerial fuel portions may be low. In a head fire, however, standing vegetation is exposed to considerable preheating and higher flames that consume greater amounts of fuel.

Anaylsis of 37 daytime backfires showed significant differences in total fuel reduction according to year. These differences were due to low consumption on some 1959 test burns where water was evident on the plot surface. A significant difference in reduction between morning and afternoon burns was also shown; afternoon burns resulted in greater fuel consumption, undoubtedly because of the lower relative humidities and fuel moistures during those hours.

Release of available fuel energy (AFE) was computed for individual litter layers. About 30 percent of this energy was produced by combustion of the fresh needles, 46 percent by combustion of the weathered layer, and only 24 percent by combustion of the decomposed layer. The fresh and weathered layers made up only half of the total litter weight and yet produced three-fourths of the available fuel energy. The greater consumption of these layers undoubtedly resulted from their lower moisture contents. Another factor in this uneven consumption was the greater availability of oxygen in the loosely packed upper layers than in the more compact decomposed layer.

Litter Consumption and Energy Release

Regression analyses showed that the dry weight and the percent moisture content of the total litter layer could be used to predict percent of litter consumed and amount of energy released by a backfire. Calculated values of litter reduction and energy release as a function of these variables are plotted in figure 3. For these test burns, fires producing more than 2,000 B.t.u. per square foot were generally found to be damaging to pine overstories, whereas those below 800 B.t.u. per square foot usually did not consume enough fuel for effective hazard reduction. These values, therefore, were used as limits on the graph.

Release of available fuel energy from the litter layer was directly related to weight and inversely related to moisture content. As fuel moisture drops, less energy is needed to drive off water, more fuel is burned, and more energy released. A decrease in litter weight resulted in a decrease in energy release (even though percent reduction increased) because less fuel was actually burned.

Vegetative Reduction and Energy Release

Vegetative fuel reduction was very erratic for some species and was not related to litter reduction; therefore, only average reduction data are mentioned here. Reduction of wiregrass fuel was complete each time the fire burned through the sample area. The moisture content of the average wiregrass sample was 56 percent, and the weight burned was 55 grams per square foot. This weight indicates an energy release of about 550 B.t.u. per square foot.

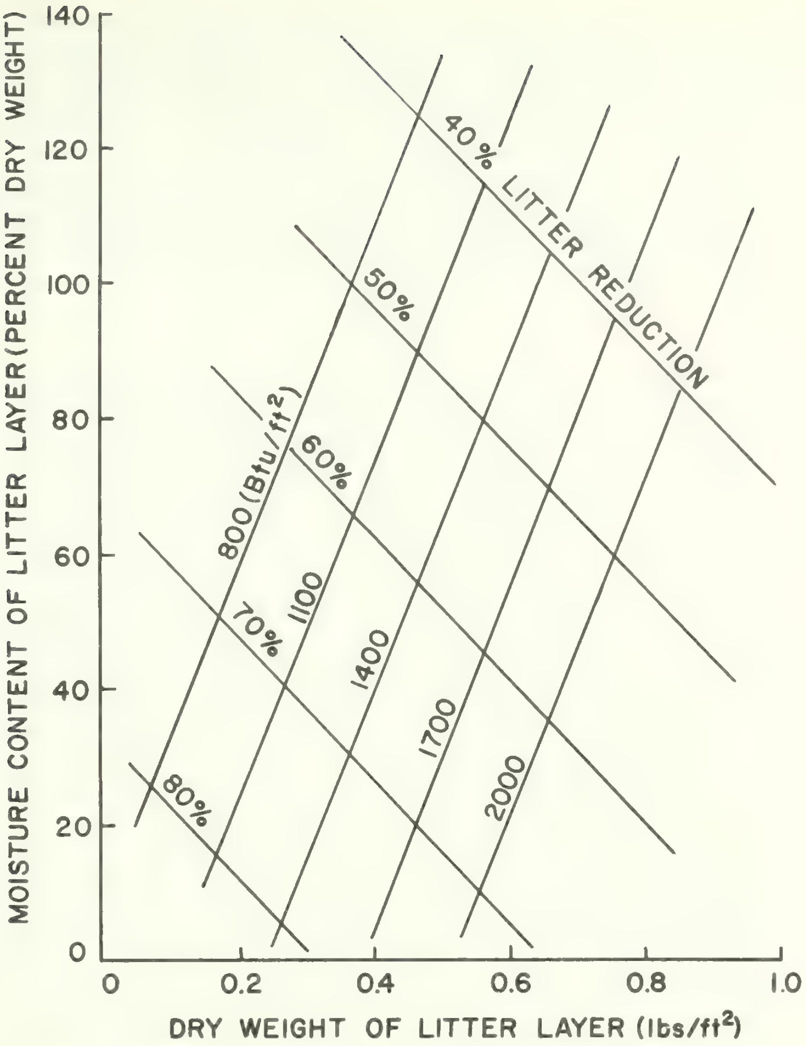

Figure 3.--Estimated litter reduction and release of available fuel energy (AFE) produced by backfires in the Coastal Plain.

Gallberry fuel reduction ranged between 0 and 70 percent. On sample plots showing no reduction, field observation indicated that backfires burned under the plants and only scorched the leaves. The moisture content of the average gallberry sample was 84 percent, fuel reduction was 38 percent, and the weight burned was 12 grams per square foot. This consumption would add about 135 B.t.u. per square foot to available energy.

Palmetto reduction was significantly related to moisture content of the plant. As moisture content increased, consumption decreased. The relationship was not strong enough, however, to serve as a basis for accurately predicting palmetto reduction. Average moisture content of the palmetto samples for the 3 test years was 123 percent, with a fuel reduction of 62 percent. The burned fuel weighed 40 grams per square foot on the average and released 395 B.t.u. of energy per square foot.

Because the reduction of vegetative material proved difficult to predict quantitatively from environmental-fuel variables, the ability to predict litter reduction rather precisely may be quite important in estimating energy release. The contribution of vegetative fuel, nevertheless, cannot be ignored. In this study, the contribution of vegetation to heat energy release amounted to about 100 to 500 B.t.u. per square foot, depending on the specific fuel involved. This heat release was in addition to the 800 to 2,000 B.t.u. per square foot produced through combustion of the litter layer.

Rate of Spread

Analysis of data on rate of spread of backfires indicated that this rate had no significant relationship to the dry weight or the moisture content of the whole litter layer. Regression analyses incorporating moisture data from individual layers of litter, however, indicated that these moisture contents were significantly related to rate of spread.

As was expected, moisture of the fresh litter was significantly related to relative humidity and the number of days since at least one-quarter inch of rain. This relationship served as a means of predicting the rate of spread of backfires (fig. 4). Either moisture content of the fresh litter or days since rain could be used with relative humidity to predict rate of spread. For example, if relative humidity measures 50 percent and 3 days have elapsed since rain, backfire spread should average about 1.6 feet per minute. Moisture content of the fresh litter should be about 27 percent under these conditions. In cases where it is difficult or impossible to gauge the number of days since rain, a direct measurement of the moisture of the fresh litter would be necessary in order to predict rate of spread of the backfire. For example, if the moisture content measured 15 percent and the relative humidity was 30 percent, backfire spread should average about 2.4 feet per minute.

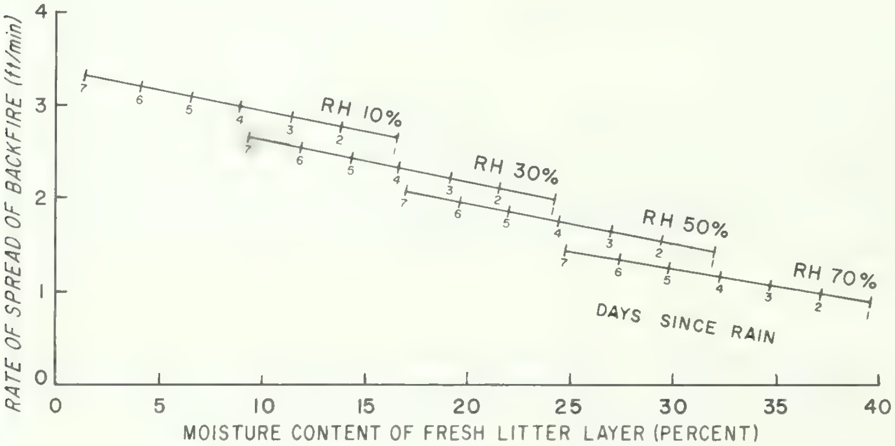

Figure 4.--Rate of spread of backfires is a function of relative humidity, adjusted for either moisture content of the fresh litter layer or the number of days since one-quarter inch or more of rain.

Rate of spread of backfires did not change for wind speeds between 0 and 8 m.p.h. (measured in the stand at eye level). The same uniformity was noted in laboratory crib fires[4] and in needle bed burns (see footnote 3).

Fire Intensity

Fire intensity may be calculated from the equation

$$I = Er$$

where E is the available fuel energy and r is rate of spread.[5] Intensity values computed from values of available energy and rate of spread for each backfire ranged from 5 to 124 B.t.u. per second per foot.

Byram[5] states that for prescribed fires burning into the wind, intensities probably range from 19 to 58 B.t.u. per second per foot. The estimated intensities of approximately one-third of the test burns made during this study fall outside Byram's range. It appears from observations conducted during the study that a wide range in backfire intensities, possibly from 20 up to 90 or 100 B.t.u. per second per foot, will give satisfactory results. Unwanted damage to the timber stand may occur if intensities rise above this limit, especially if wind speeds are low.

SUMMARY

Hazard reduction burns were conducted over a 3-year period in the Georgia Coastal Plain. Information was collected on the influence of fuel and weather variables on fuel consumption and energy release.

Results indicate that the percent of litter reduction and the output of fuel energy from backfires in litter fuel may be estimated from the dry weight and the moisture content of the total litter layer. It was also found that 76 percent of the total available fuel energy was released from the fresh and weathered litter layers, which made up only 50 percent of the dry weight of the total litter.

Rate of spread of backfires was found to be inversely related to the moisture content of the fresh litter layer. Relative humidity and days since measurable rain may be used to predict the moisture content of the fresh litter or rate of spread. Wind was not related to spread of backfires in these tests.

Fire intensities were estimated from available fuel energy and rate of spread. Data from these burns indicate that fuel consumption will be poor if intensities fall below 20 B.t.u. per second per foot, whereas intensities of 90 B.t.u. or above will damage the timber stand.

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[4] Byram, G. M., Clements, H. B., Bishop, M. E., and Nelson, R. M., Jr. Final report project fire model - an experimental study of model fires. U. S. Forest Serv. Southeast. Forest Exp. Sta., 51 pp. 1966.

[5] Byram, G. M. Combustion of forest fuels. In Forest fire: control and use, by K. P. Davis. Chapter 3, pp. 61-89. 1959.

U.S.D.A. Forest Service Research Paper SE-37 July 1968

Blending Forest Uses

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COWEETA HYDROLOGIC LABORATORY
U. S. DEPARTMENT OF AGRICULTURE
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Cover Photo—*The 356-acre experimental watershed is located in the Nantahala Mountains near Franklin, North Carolina. Snow is rare, but serves here to outline truck trails and cutting patterns during logging, as seen by a walker on the Appalachian Trail. Favored by abundant sunshine and rainfall, plants and animals, the basin lies in view of some of the finest mountain scenery in the East.*

Forest Service - U.S. Department of Agriculture
Southeastern Forest Experiment Station
Asheville, North Carolina

Blending Forest Uses

by

John D. Hewlett[1] *and James E. Douglass*[2]

A trail walker in stout shoes and backpack breaks out of a green avenue of trees into a forest clearing. The view of distant mountains is splendid but the hiker is appalled by what he sees before him—a tangle of cut limbs and trunks of trees spread over the slopes below. The winding logging road reveals the fate of the green cathedral behind him. His day is ruined. But this is only one of the many wildland conflicts.

The hunter wants to hunt, the logger wants to log, the camper makes fires, and the foresters have to worry about them all. Garden club people want the area to stay "wild" but they do like gravel paths. The jeep owners want to roar through the forest, but hikers detest wheels. The wilderness organizations want everything preserved as it was in Daniel Boone's time, but when their own horses churn up the alpine meadows they begin to ask questions even of themselves.

And so the forest manager must achieve a fine balance between the many forces pulling him. He must decide which uses best fit where, and then learn which are mutually supporting and which mutually exclusive.

Not only are the users often in conflict but so are managers of the woods. A case in point is the municipal watershed that supplies forest water almost directly to city mains. In the past, purest examples of exclusive management have been practiced on such watersheds; still mindful of the cut-out and get-out methods of America's Paul Bunyan era, city water managers insisted that the only way to protect a water source was to fence it off and exclude all access. Frequently these were not unwise precautions, for old methods of road building, logging, and public access have been highly damaging to water quality. On the other hand, the dangers of contaminating water during well-planned forest operations have been exaggerated, and forest managers now argue for multiple management objectives even on municipal watersheds. The case for multiple use is growing, but so are the conflicts.

Out of all this is emerging the great need to learn how to produce optimum benefits for everybody. With sufficient knowledge, several uses can be put together—some will even strengthen others. But with the hit-or-miss methods of the past, the forests of the United States are in danger of producing less of everything for everybody.

Part of the confusion surrounding forest use stems from the scarcity of concrete examples of multiple-purpose management; i.e., the lack of distinct pieces of land managed by design, rather than by expediency, for several purposes. Without attempting to settle any controversies surrounding land-use economics, we (the authors) designed an experiment at the Coweeta Hydrologic Laboratory to provide a small working model of multiple-purpose management on a forested watershed.

The experimental location is a 356-acre watershed high on the main ridge of the Southern Appalachians, near Franklin, North Carolina (fig. 1). Soils are granitic, deeply weathered except at the higher elevations, and quite permeable. Annual rainfall is perhaps the highest in eastern America, averaging from 80 inches in the cove to 100 inches at 5,200 feet elevation. Forest cover was extremely dense before management. There are 11.7 miles of stream channel per square mile of area, annually delivering streamflow equivalent to water 5 feet deep over the whole watershed. The main channel contains some small native trout which were virtually inaccessible to fishermen. Deer, grouse, turkey, squirrel, fox, wildcat, raccoon, bear, and many birds frequent the watershed.

The whole Coweeta basin, of which this watershed is part, contains 5,000 acres, a complete set of gauges for recording rainfall, and some 30 stream gauges that have been measuring water yield continuously for 30 years. Based on past records, the effect of forest cutting upon water yield can be determined accurately (fig. 2).

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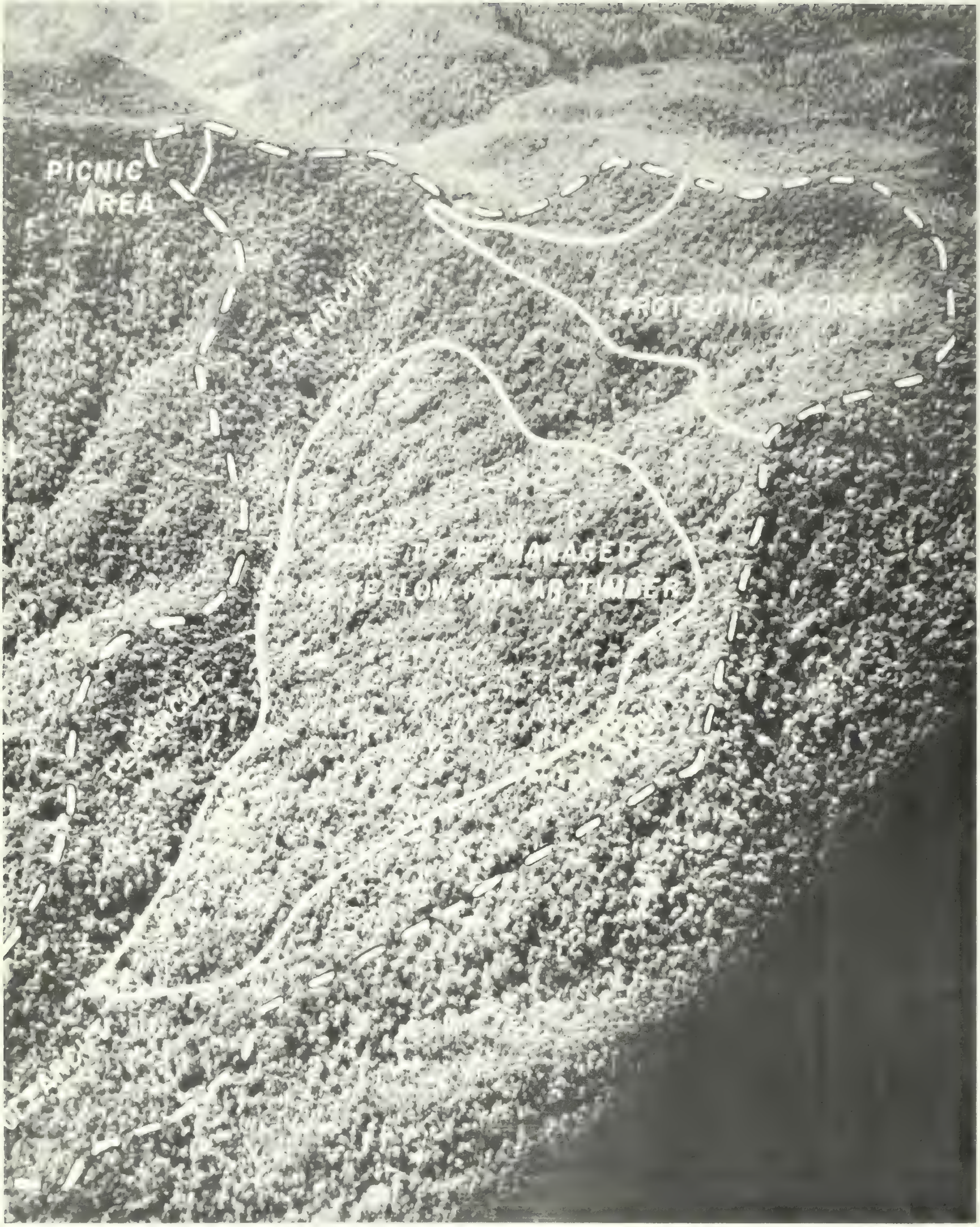


Figure 1.—*This watershed is typical of inaccessible, high elevation forests of the Southern Appalachians. It was divided into the compartments shown for management of water, timber, wildlife, and recreational resources.*

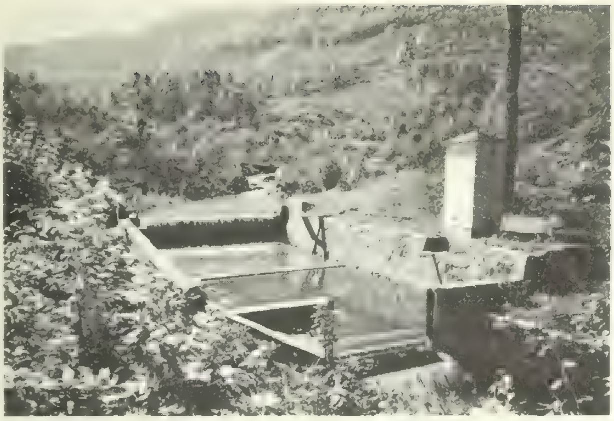


Figure 2.—*All water flowing from the experimental watershed was measured at this sharp crested weir for 11 years prior to management. After the relationship between flow from this and an adjacent control watershed had been determined, management began. Thus the measured changes in streamflow are known to be caused by management of forest resources.*

How did we select objectives and delineate the areas of conflict among uses? In the absence of agreement among policy makers and users, we attempted to select a reasonable set of objectives and apply them primarily to evaluate conflict among uses and also to show how forest resource management might be practiced in the years to come. We chose the uses to which the land seems best suited; namely, water production, timber production, hunting, fishing, hiking, and picnicking.

ACCESS THE KEY

An obvious requirement in any program of resource management is access. If people cannot get into an area or products cannot be removed economically, little management is possible. But access is too often secondary in planning, as if it were brought on by an immediate rather than a continuing need; roads are planned and constructed under pressure of a specific use, or a set of needs all related to a particular tract of land. Consequently, some tracts are overlooked or served inefficiently by poorly located roads and trails. Many of these must be relocated at great cost and disturbance each time a new management phase begins.

This has been particularly true of logging roads, skid roads, and truck trails in mountain forests. Layout and road location have often been left to logging contractors or their skidders or bulldozer operators, who had no thought of the future. Their trails went the easiest way—down the dip, into the stream, with no water-turnouts and frequently no possibility of any. After the timber sale, water ran down the abandoned tracks for as much as a mile, gathering volume and velocity, scouring out the roadbed. Such access routes could not be used again, and when another timber sale took place, perhaps 25 years later, new roads and trails had to be gouged out. That is why access is the key, and why we put roads and trails first in the management plan.

It is not enough merely to plan a road to serve several purposes along its route; rather access should be planned to serve a forest area for all anticipated uses of that area. The first criterion is planning access into the largest tracts of land possible. When boundaries permit or agreement among owners can be arranged, the most efficient access is to fit the road layout to the major features of the terrain rather than to management compartments. In mountainous country, well engineered climbing forest roads should be spaced 3 to 5 miles apart to provide access to all elevations. The climbing forest road should be laid out to climb secondary ridges rather than to follow the main stream channels. In this experiment, we assumed that the existing forest road was planned this way to serve the entire Coweeta basin.

Next is planning access to serve not only the current timber harvest but all potential uses and protection needs. The cost of initial development should not be charged against timber values only or other immediate resource needs, but against anticipated uses over the next 50 years at least. Although this implies some difficult choices to be made about future use of the area, it is hard to see how these choices can be avoided.

Third is designing the system around specified classes of roads and trails, taking into account adequate entry by foot or vehicle to all parts of the basin as well as the need for maximum access during timber harvest. The only class of road readily agreed on by most forest engineers is the graded, drained, and surfaced forest road referred to in most manuals. These are usually well engineered and maintained to prevent improper use, erosion, and deterioration. But the damage to streams and other watershed values usually occurs from spur roads and skid trails of vague classification which are constructed and maintained by equally vague standards. Classification and improvement in design of these producer roads and trails is a major need in forest engineering.

The final criterion is planning for a reasonable degree of regulated vehicle access by contractors and the public. In the past, haphazard road and skid trail systems developed during a timber sale have often been left open to vehicle use in all kinds of weather. Even logs across the trails and lack of bridges at streams have failed to prevent vehicular use of abandoned logging roads and trails, which gradually become a hazard to the unwary public and nuisance to the manager, to say nothing of the damage to streams and the road itself. An orderly classification of roads and a clear plan of maintenance and closure will reduce these problems. Obviously when the cost of repairs exceeds the value of access by vehicle, truck trails should be closed either temporarily or permanently. Signs should be used to inform the public why closure is necessary.

These criteria lead to recognition of five classes of road—the forest road, the climbing truck trail, contour truck trail (both permanent and temporary), tractor skid trail, and foot trail. Climbing truck trails are undesirable but are occasionally necessary to give elevational access where property boundaries or other barriers prevent extension of contour truck trails to forest roads. Contour truck trails branch from climbing roads at horizontal intervals of 600 feet or greater, depending on steepness of the terrain. Tractor skid trails are developed downward from contour trails but are restricted to ridgetops between streams. Areas too steep or rugged to allow economical access by vehicle are served by foot trails to the extent necessary to protect the forest and allow people to enjoy it. A summary of specifications used to design the trail system is listed in table 1, and the resulting layout depicted in figure 3. Foot trails are not listed, since the existing Appalachian Trail serves the only part of the unit not reached by vehicle. It is intended that the truck trail system shall never need extension or relocation on this watershed, and since expensive maintenance of truck trails often becomes impractical, the trails are constructed to be relatively maintenance free.

Because of the minimum maintenance requirement, broad-based dips are a key feature of the truck trail system. They prevent destruction of the roadbed by intercepting surface water and turning it out of trails before it gains sufficient volume and velocity to cause serious erosion. They must be deeper than is usually considered adequate for water bars, because water bars fill up quickly or are cut through by heavy trucks. These broad-based dips were designed especially for Southern Appalachian conditions, but they should serve well elsewhere. Specifications for constructing dips are new and are illustrated in figure 4.

A dip is made by building a 20-foot-long, 3-percent reverse grade (0.6 foot dip in elevation) into the truck trail. The trough of the dip is outsloped at 3 percent to keep water from standing in the bottom. There must be at least 100 feet of forest soil between the dip and the stream to absorb water and to trap the silt it carries. Dip spacing is made a function of the basic grade of the truck trail—the steeper the grade, the closer the spacing of dips. However, experience has

Table 1.—*A summary of specifications for truck and tractor skid trails into a mountain watershed. These trails are in addition to forest roads, whose construction is governed by existing standards*

Specifications	Climbing truck trails	Contour truck trails[1]	Tractor skid trails
Route layout	Forest Officer	Forest Officer	Operator subject to approval
Stream crossings	Avoid	At right angles on dipping grades with culverts	Not permitted
Grades	13 percent maximum	Least practical	None specified
Right-of-way	Clear 24 feet	Same	Least possible
Slash disposal	Pile at toe of fill slope	Same	Lay back in trail
Backslopes	Leave vertical	Same	Not permitted
Curves	Not less than 25-foot radius	Same	No limit
Cut and fill	Wheel track on cut soil	Least practical	Not permitted
Broad based dips	Spacing = 400/slope percent + 100 (in feet)	Take advantage of local terrain	Not permitted
Outsloping	3 percent	Same	Not permitted
Surface	Coarse gravel on steep pitches (dips)	Shoulders grassed	Keep dozer blade out of soil
Inside ditching	Usually none	Only at stream crossings	Not permitted
Traffic control	Gated during bad weather	Same	Only by foot after logging
Maintenance[2]	Inspect annually; repair dips; fertilize as needed	Inspect culverts annually; fertilize as needed	None required

[1] Temporary contour truck trails constructed just as permanent contour truck trails but "put to bed" at completion of logging.

[2] At end of logging, all permanent truck trail surfaces should be dressed, fertilized, and seeded.

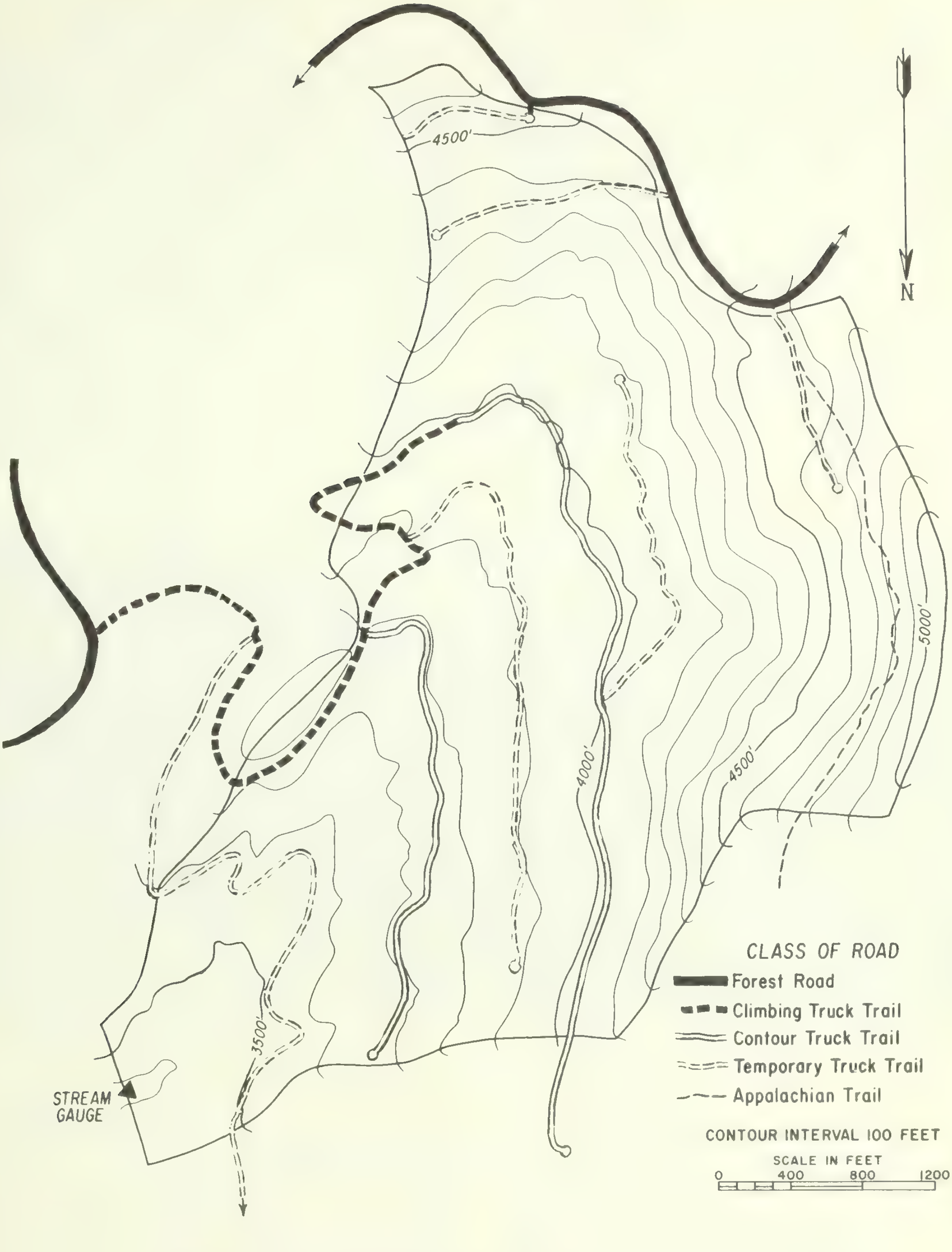
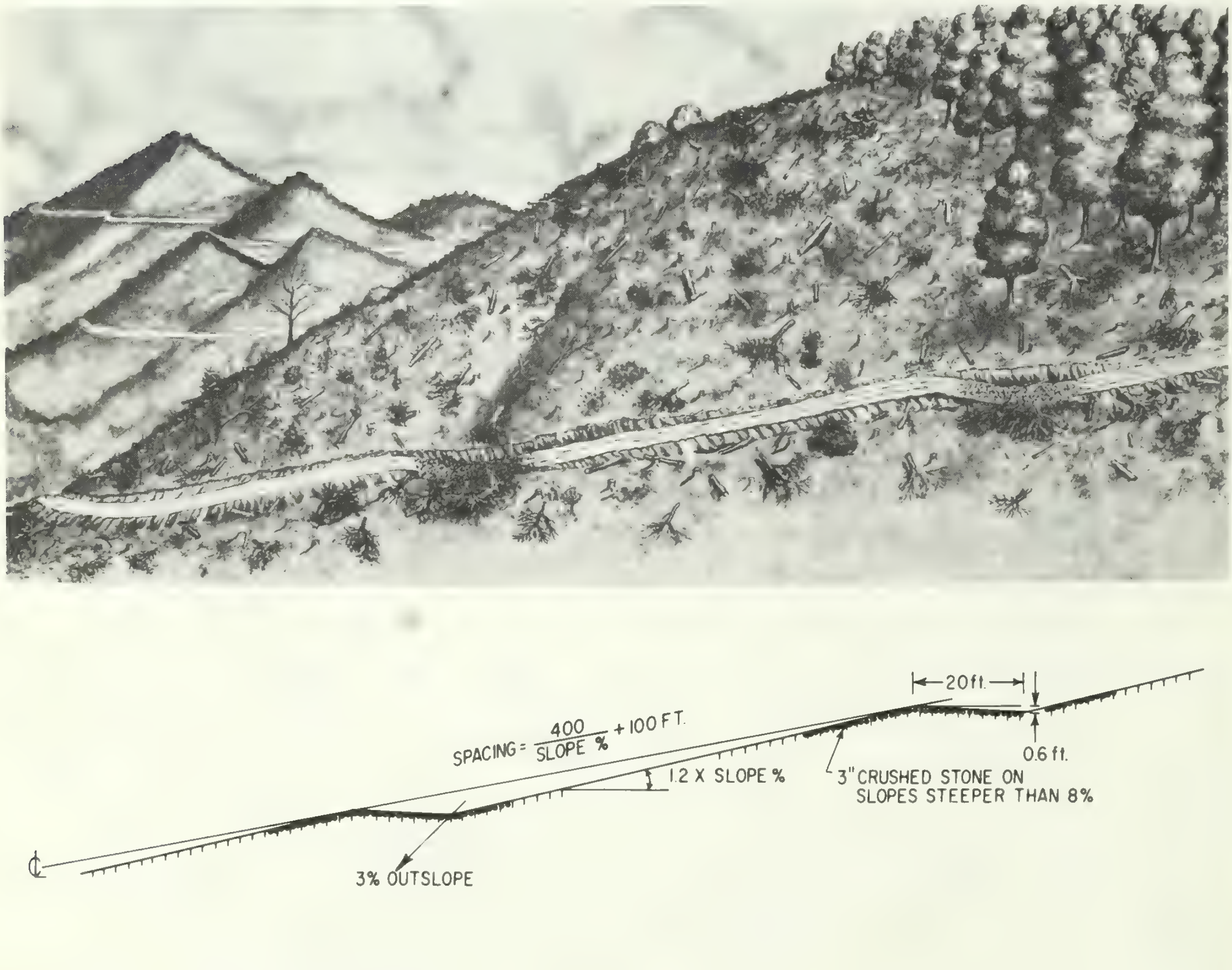


Figure 3.—*Access is a key feature of multiple resource management. The truck trail system constructed during this study recognized the need for continuing, essentially maintenance-free access for all potential uses and protection needs—a road system which will never need relocation or reconstruction.*

shown that trucks have difficulty negotiating dips constructed on basic grades steeper than 13 percent. Also, since the grade between dips increases by a factor of 1.2 times the basic grade, erosion on steep pitches of a climbing contour truck trail becomes a problem. On grades steeper than 8 percent, a thin layer of 3-inch crushed stone over the peak and trough of the dip provides an effective erosion pavement which prevents rutting and soil movement during and following logging. Gravel small enough to be lifted and carried by water will not do. On contour trails, dips may be much less frequent and the dozer operator can vary dip spacing to take advantage of natural depressions in topography. Inspection and occasional repair of these dips becomes one of the few road maintenance jobs, but experience has shown that little maintenance is necessary when the basic grade is limited to 13 percent.

MANAGEMENT BY COMPARTMENT

No one knows for certain how these lands will be used 50 years from now. We can only conclude that demands on the resources of the Southern Appalachians will certainly include water, wildlife, recreation, and timber. To simplify planning, we have assumed that the objective of management will be to produce the optimum combination of these resources over the next 50 years or so. None of the objectives should lead to practices which will slowly destroy watershed resources, since this would severely limit the choice of uses by managers of the future. Because different portions of the watershed produce resources in differing amounts and qualities, the first step was to divide the area into its natural components or compartments (fig. 1).



SPACING = $\frac{400}{\text{SLOPE \%}}$ + 100 FT.
20 ft.
0.6 ft.
1.2 X SLOPE %
3" CRUSHED STONE ON SLOPES STEEPER THAN 8%
℄
3% OUTSLOPE

Figure 4.—*Broad-based dips turn the water out of forest roads. A key feature of the truck trail system, they are designed to require almost no maintenance.*

In the highest compartment, the forest stand is composed of low-quality northern red oak and a dense laurel-rhododendron understory. Trees are short and branchy because of repeated ice damage, and the growth potential is low on these steep, rocky, shallow soils. The Appalachian Trail passes through this compartment and the view is splendid. Protection of wildlife and recreation values appeared to be the most suitable management.

Poor oak-hickory stands on the lower slopes were producing little timber or browse, but soils were deep, well watered, and capable of timber production. Plans call for regeneration of the timber stand and production of additional water and browse. Clearcutting all woody vegetation after harvesting merchantable timber was prescribed to accomplish all three objectives simultaneously.

The cove contained a 40-year-old stand of excellent yellow-poplar mixed with over mature remnants of other hardwoods. Foresters estimate that the yellow-poplar will be from 85 to 120 feet high at age 50, but the growth rate of the overcrowded stand had slowed appreciably during the last 7 years. An improvement cut was prescribed to increase growing space for crop trees, as well as an understory cut to increase water yield (fig. 5). These cuttings were also intended to produce additional game forage and open the stand for better views. Additional cuts will be made at 20-year intervals, and perhaps 40 years hence the cove site will be clearcut in accordance with principles of even-aged management—then to regeneration of yellow-poplar or other desirable species.

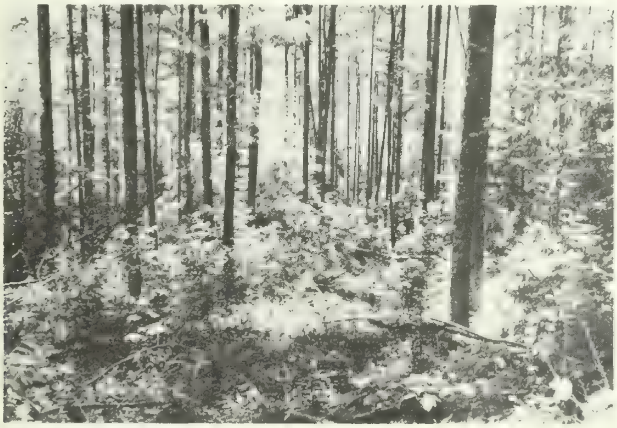


Figure 5.—*Yellow-poplar in the cove compartment was crowded and growing slowly when the study began. Overtopping wolf trees were cut or girdled, the overstory was thinned, and the understory was cut. After 2 years, the vigorous, young sprouts and seedlings all but obliterated signs of the tractor skid trail (center foreground).*

Management of the fisheries resource involves only 3/8 mile of the main channel in the cove compartment, which contained perhaps 50 to 100 small native trout. Although the practicality of fisheries management on such a small scale is doubtful, this attempt serves to illustrate possibilities on a larger working compartment, and two prescriptions were made. First, the tangle of brush and old logging debris was removed from the channel to improve access to and appearance of the stream. Second, small fish dams were installed at irregular intervals to improve the ratio of pools to riffles and to provide deeper water to harbor the trout (fig. 6). Streambank vegetation is expected to recover quickly to shade the stream, but occasional trimming of overhanging brush should keep sufficient opening to allow a fisherman to work his way down the channel. The remaining 5 miles of brooks and freshets are to be maintained as they are—brushy, partially blocked with debris, and virtually inaccessible except at trail crossings.

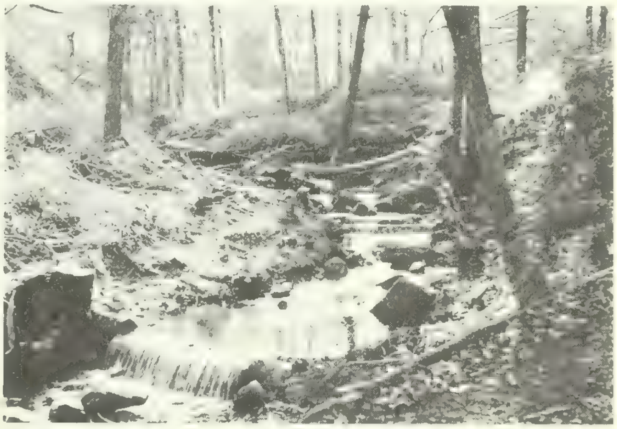


Figure 6.—*The lower 3/8 mile of the main stream was cleared of old logging debris and opened up for trout fishing. Small log dams such as this were installed to create ripples above and pools below the dams. Channel scour and bank cutting near these structures accounted for most of the increased sediment in the water.*

Management prescriptions were carried out in conjunction with logging. The trail system was designed with the idea that all logs would be cabled uphill to the contour truck trails. But this was not always practical. Where possible, trees were cabled to the trails and sawed into logs along the shoulders. Where the distance was too great, tractor skid trails were permitted downward along ridgetops. Dozer operators were instructed as a general rule to keep dozer blades ***out of the ground*** when off the truck trail, and downhill skidding with tractors was generally prohibited. Trees within 100 to 200 feet above were felled into the truck trail; rarely was the tractor permitted to skid short distances downward. Fording or skidding across streams was strictly prohibited. The operator found these restrictions reasonable and often advantageous to the maintenance of valuable equipment and safe operations.

Logging was carried out between August 1962 and July 1963. Only about 30 days of down-time occurred during the rather wet, cold winter. Traffic was restricted during exceptionally wet and thawing weather, but because of good grades and careful construction of the truck trails there was no conflict with the operator over closure; it was quite apparent when the roads were impassable.

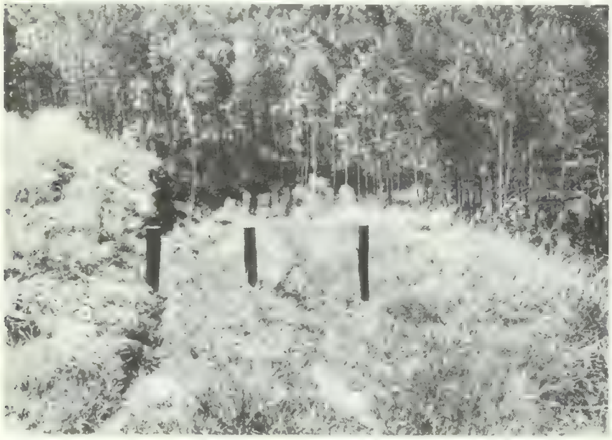


Figure 7.—*To stabilize exposed soil after the logging, truck trails were planted to grass. Temporary truck trails were not needed between cutting cycles and were closed to vehicular traffic to reduce maintenance cost. They continue to serve as attractive walking trails for hikers and shooting lanes for hunters, and can be quickly reopened when needed.*

As each contour truck trail was logged out, the road surfaces were dressed, fertilized, and seeded to Kentucky 31 fescue grass, a hardy species with good soil protection characteristics (fig.7). Outsloping tended to disappear under loaded trucks and had to be reshaped. Alternate contour truck trails were completely closed out. Prescribed maintenance calls for annual inspection of drainage structures, including the broad-based dips, and the use of fertilizer to aid vegetative stabilization of slopes, fills, surfaces, and slumping inside banks. The truck trail system was designed to eliminate road grader maintenance; the broad-based dips and grass cover make road graders unnecessary. The watershed with all construction and initial prescriptions completed is shown in figure 8.

THE IMPACT OF MANAGEMENT

Perhaps the major consideration in watershed management is to maintain water quality during management for other resources. The granitic soils of the Nantahala Mountains contain limited amounts of clay to muddy the water. However, annual litter fall produces some organic debris to cloud the streams. Storms normally wash these organic materials into the streams, along with some coarser soil particles from the channels themselves. However, streams clear quickly even after heavy storms, because the coarse material drops out as soon as the peak flow passes. Between storms, suspended material was less than 8 parts per million, both before and after construction of roads and channel improvements. Some intermittent water sampling included observations during two severe storms in September and October 1964. These storms were of the intensity expected only once every hundred years. They produced, however, only one and a half times as much suspended material from the experimental watershed as from an adjacent undisturbed control watershed.

Nearly 5 miles of new roads crossed live streams many times, and water draining from roads carried some soil into streams during road construction and logging. However, the major part of the increased sediment was traced to "stream improvement" operations. Removal of old logging debris and construction of about 36 fish dams caused entrenchment of the channel and erosion of the banks. Channel stability is delicate and unpredictable in small, steep streams. It is not clear that stream improvement prescriptions applied here have done any good, and they may have done some harm. The methods are controversial, the returns are intangible, and therefore we do not recommend "channel improvement" on such small streams without further study.

Even though management operations were exceptionally intense, the additional sediment produced is minor insofar as on-site erosion and downstream water quality are concerned. Although there appear to be no serious consequences from the slight increase in sediment, it must be pointed out that we know little about the effect of small amounts of sediment on fish management. Peak stormflows and stormflow volumes were virtually unaffected by the forest operations on this watershed.

Another objective of water management was to increase the volume of clean water flowing from the watershed. The control watershed method was used to estimate the additional water produced. The relationship between monthly streamflow from the experimental unit and from an adjacent control

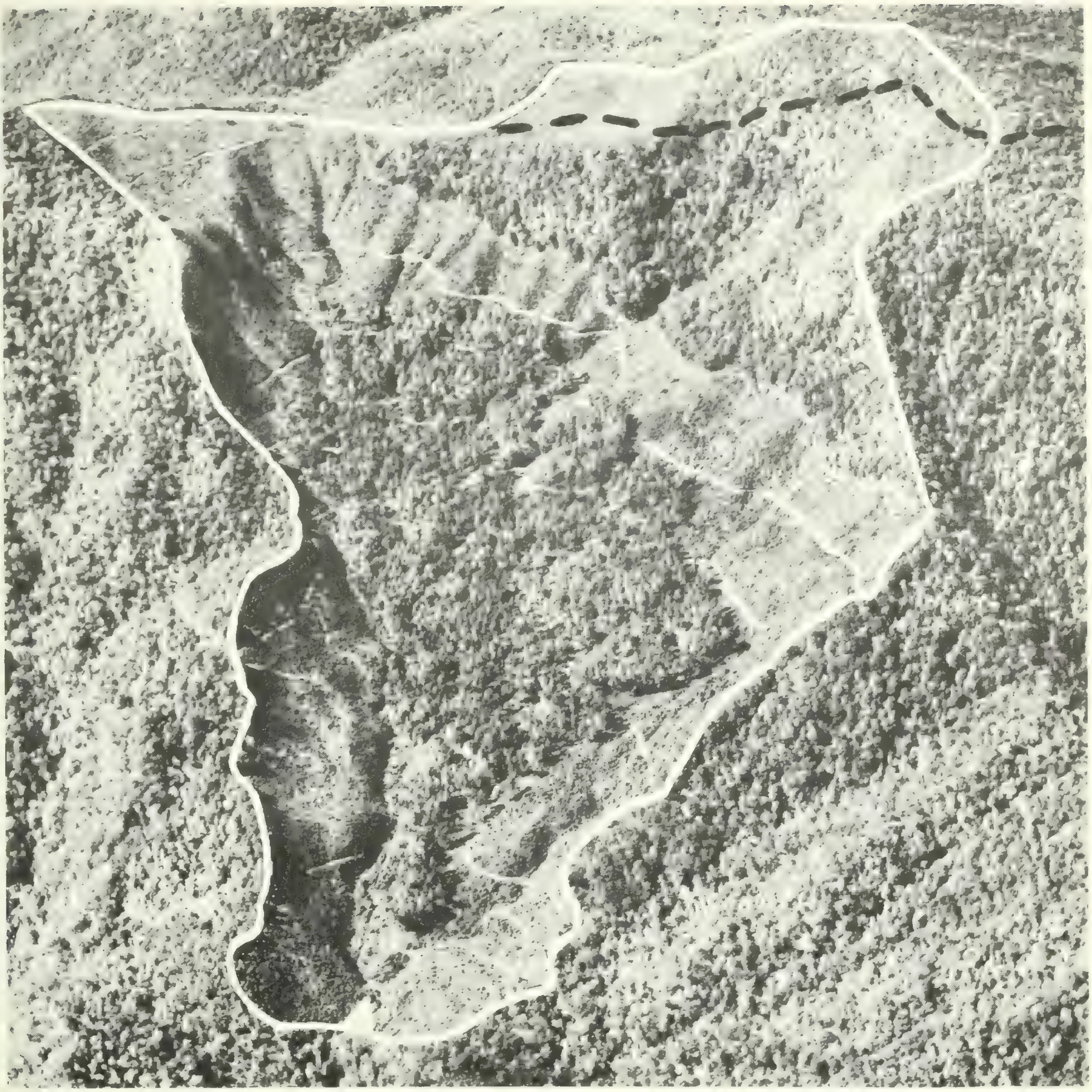
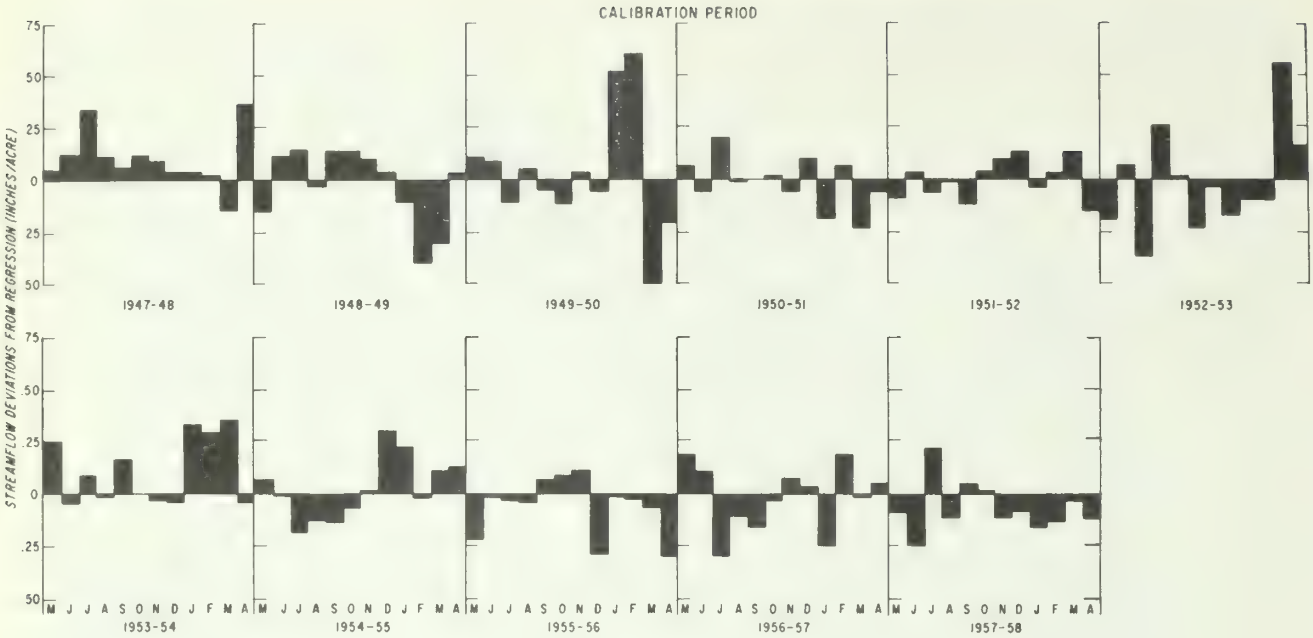


Figure 8.—*In the center is the thinned yellow-poplar area. It is surrounded by the clearcut compartment, which contained overmature oak and hickory, often with understory thickets of laurel and rhododendron. The weir is indicated by the arrow (lower center). Just above center is the uncut protection forest, too steep and infertile for commercial timber production. The Appalachian Trail winds along the background ridge (black line).*

watershed with similar terrain, climate, soils, and vegetation was established during an 11-year period before management. The difference between measured flow after management and flow predicted from this relationship shows how streamflow increased.

Past experiments have measured the large quantities of water used by trees, shrubs, and grass. Past experiments also prove that water use is reduced and streamflow is increased roughly in proportion to the percentage of the watershed cleared or percentage of the original vegetation cut. Therefore, thinnings and understory cutting also increase streamflow. Analysis of the first year's streamflow after clearing showed an increase of 6.2 inches, or 184 acre-feet, from the whole watershed. To put the annual increase in more practical terms, the extra water produced during May 1963 through April 1964 would



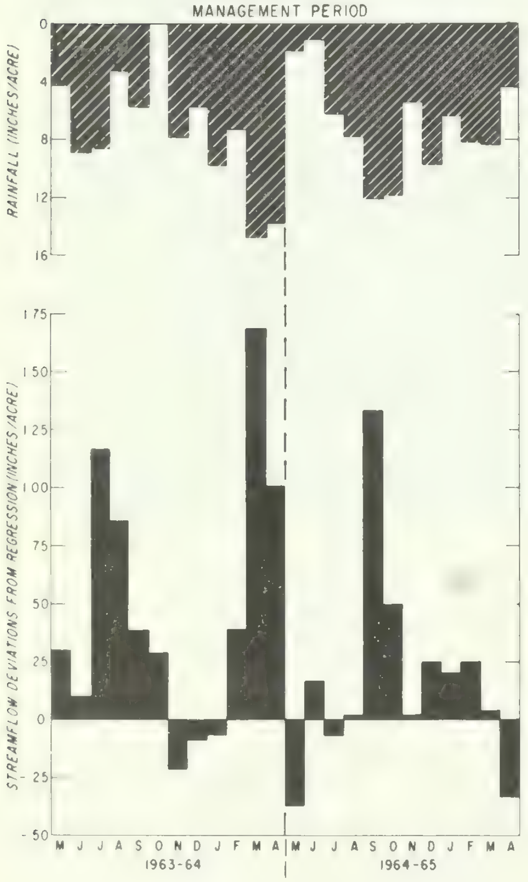


Figure 9.—*Water flow out of the experimental basin was predicted from an adjacent watershed by regression analysis. This bar diagram shows how accurate such a prediction can be. During the calibration period (from 1947 through 1958) the plus and minus deviations from the zero lines (above) represent random errors in estimating monthly total streamflow from the not-yet-managed watershed. During the management period (left) the solid black bars represent the deviations of streamflow from the relationship established in the calibration period. The large positive deviations can only mean an increase in streamflow, which in some months was larger than one inch of additional flow. The greatest increase in flow occurred during months receiving heavy rainfall (hatched inverted bars), showing that new supplies of rain are needed to flush the water savings through to streams.*

meet the normal water requirements of about 1,100 people for a similar period. At the average value of irrigation water, about $12 per acre-foot, the additional water would be worth $2,200. But at the present cost of desalting sea water, about $327 per acre-foot, the additional water might be worth $60,000.

Monthly increases can be shown as deviations of actual flow out of the managed watershed from flow predicted by the adjacent undisturbed watershed (fig. 9). These deviations are plotted for both the previous 11-year calibration period and the management period to show clearly the effect of cutting. A zero deviation during the management period means that flow has not changed from its original relation to the control watershed. The positive deviation of 1.6 inches during March 1964 indicates that 16 million gallons of extra water were produced that month. These large monthly increases are correlated with monthly rainfall, plotted above the streamflow changes in figure 9. Although evapotranspiration reduction after cutting trees occurs largely during the summer, a supply of new rain is required to flush these savings into streams; otherwise, the savings may remain locked in the soil for periods up to 6 months or more. In other words, it takes water to fetch more water. Large rains in July and August 1963 flushed early summer savings into streams almost immediately, but a dry fall delayed further increases in yield until March and April of 1964. These delays in delivery bear importantly on management for increased streamflow, which will be subject to the vagaries of rainfall both as a primary supply and as a carrier of savings brought about by evapotranspiration reductions. This means that a crash program to control evapotranspiration by cutting trees cannot be expected to relieve an emergency water shortage.

As vegetation regrows, water-yield increases will diminish, although an earlier study showed that recession to premanagement levels requires about 35 years. Since cyclic cuts are planned, streamflow should remain above premanagement levels indefinitely.

Turning to the timber resources, the 180-acre clearcut now supports vigorous sprouts and seedlings. A survey showed that cove species have spread outward, adding about 40 acres to this valuable type. Northern red oak and yellow-poplar, two of the most valuable native timber species, comprise 45 percent of all new growth in the cove extension (table 2); these will be favored for future crop trees. Yellow-poplar crop trees may be selected from either seedling or sprout origin

Table 2.—*Seedlings and sprouts per acre in the clearcut compartment 2 years after clearcutting. Desirable browse species are marked with an asterisk*

Species	Cove extension			Upper slopes		
	Seedlings	Sprouts	Total	Seedlings	Sprouts	Total
	Number					
Northern red oak	2,253	64	2,317	1,725	244	1,969
Yellow-poplar*	1,100	400	1,500	150	50	200
Red maple*	920	100	1,020	382	376	758
Birch	400	90	490	196	102	298
Hickory	170	40	210	37	88	125
Buffalo nut*	150	0	150	11	0	11
Chestnut oak	141	38	179	201	95	296
Black locust*	140	390	530	27	267	294
Witch-hazel*	140	50	190	46	75	121
Ash*	130	50	180	72	108	180
Rhododendron	100	130	230	34	285	319
Black gum*	80	50	130	22	49	71
Cucumber tree (Magnolia)	80	0	80	18	0	18
Sassafrass*	80	120	200	96	158	254
Black cherry	60	0	60	130	127	257
Dogwood*	60	120	180	18	50	68
Sugar maple*	40	40	80	65	77	142
Scarlet oak	26	38	64	102	60	162
White oak	13	64	77	32	11	43
Service berry*	10	20	30	5	34	39
Striped maple*	10	20	30	4	7	11
Spicewood*	0	120	120	0	45	45
Sourwood*	0	80	80	18	36	54
Azalea*	0	0	0	0	195	195
Viburnum*	0	0	0	0	36	36
Other	70	300	370	18	495	513
Total	6,173	2,324	8,497	3,409	3,070	7,479

because both are sufficient for the future crop. A precommercial thinning is planned in about 5 years to release crop trees from competing vegetation, particularly maple sprouts, and to boost browse production and water yield.

Forest reproduction on upper slopes of the clearcut compartment is oak, maple, birch, locust, black cherry, and ash. Northern red oak and black cherry will be favored for crop trees here. As in the cove extension, a thinning is planned to release crop trees from competing vegetation. Thinning will again increase browse production and water yield.

Harvesting and thinning left the cove in excellent condition. The stand now consists mostly of well-spaced, vigorously growing yellow-poplar. The stand will be thinned for saw logs in about 20 years and will be completely harvested in about 40 years, at which time a new crop will spring up.

No game census was planned as a part of this study, but observations of animal tracks in truck trails testify to heavy use of the area by deer and other species. This is not surprising, because prolific sprouts and seedlings provide more abundant and desirable browse than the surrounding old forest. More than half of all woody reproduction in the cove extension is classed as desirable browse; on the upper slopes one-third of the reproduction is desirable (table 2). Studies elsewhere in the Southern Appalachians suggest that similar clearcutting produces 1/2 to 1 ton of browse per acre cut, which is more than 20 times the browse available in unbroken forest. Although some succulent sprouts are being nipped by deer, browsing is not a limiting factor in regenerating the new timber stand, because more food is available than the deer can eat. Later thinnings scheduled for timber management purposes should continue to improve browse productivity.

Hunters favor the area because of good views for sighting game and easy walking access. The watershed is hunted almost every day during deer season, but we have no record of kills. Local fishermen have found access to the lower channel much improved. There is no evidence that any wildlife has suffered because of the restructuring of the forest stand; the abundant browse and cover suggest the opposite.

Picnicking is permitted but not encouraged on the experimental area, chiefly because there is no provision for the policing needed. Pleasure drivers and hikers have generally been interested in the openings and the patterned cutting. Although many were offended at first by the slash, the clearings, and the zigzag trail system, 3 years' growth have largely changed this picture. Logging debris is always unattractive, but as long as snags are not left standing, the slash rots quickly under the regrowing forest (fig. 10). Although opportunity for recreation was increased for many people by management, chiefly because it is now easy to travel over the area, the quality of recreation may have diminished for a few. Interpretative signs along the Appalachian Trail and at overlooks inform visitors of the purpose of the experiment; such public information tends to alleviate hasty criticism and encourages public involvement in the necessity for well-planned management of public lands.

THE COST

Emphasis in planning was on determining physical feasibility of management for several purposes rather than on analysis of cost benefit ratios or economic justification. Furthermore, the ultimate test of the economics of multiple-purpose management must be performed on large areas within real management situations.

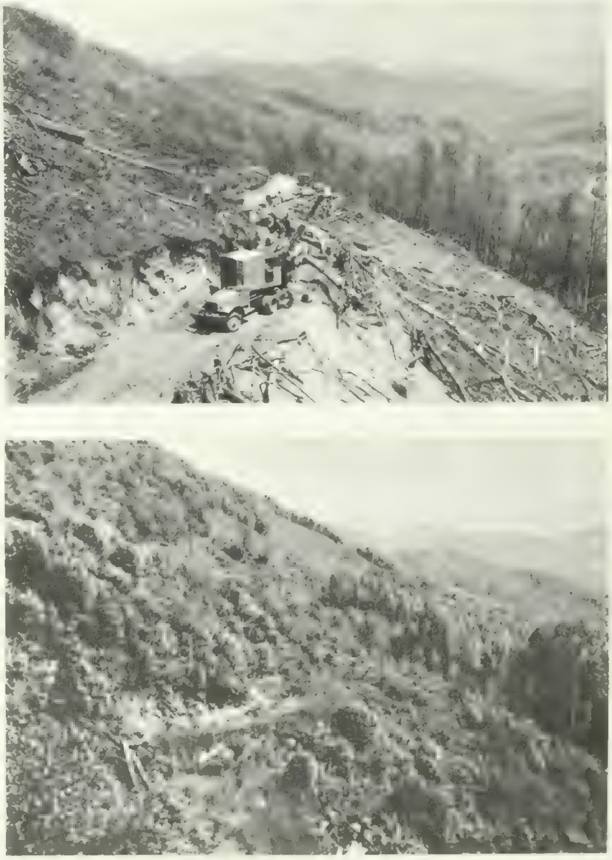


Figure 10.—*Uphill logging is recommended for steep lands. Tractors skid trees uphill to truck trails where they are bucked into logs, scaled, and loaded onto trucks. The aftermath of a clearcutting is unsightly, but 3 years of regrowth by the new stand hid the logging debris under a green canopy.*

Nevertheless, cost of development and value of products removed during the initial phase of management were obtained. The logging contractor supplied us with logging costs and a lumber tally. All other phases of management were accomplished under Accelerated Public Works financing, and cost records were available. A summary of costs and income is presented in table 3.

Truck trail and clearcutting costs require some explanation because they were unusually high. Truck trails were built from November to April during snowy, rainy, freezing, and thawing weather. Similar trails are routinely built during the summer and fall months for about $4,000 per mile, but construction during adverse weather raised costs to $5,153. Time limitations on APW funds and delay in negotiating the timber sale forced most clearcutting to be done before logging and pulpwooding, and increased clearcutting costs from about $50 to an average of $84 per acre. Despite these problems, the value of timber products alone exceeded costs. But the current timber return is only a small part of the story, because future returns, both tangible and intangible, will be worth far more.

Table 3.—*Summary of costs and income, first phase of management*

COST

Function	Units	Unit cost	Total cost
Truck trail construction	4.64 miles	$5,153	$23,910
Clearcutting	180 acres	84	15,120
Thinning	92 acres	47	4,324
Recreation			558
Other costs[1]			3,565
Total			$47,477

INCOME

Products	Units	Unit value[2]	Total value
Timber	1,359 MBF	$34.29	$46,600
Posts	7,450 pieces	.10	745
Pulpwood	144 cords	.75	108
Fuelwood	162 cords	.50	81
Water	184 acre-feet	12.00[3]	2,208
Wildlife			Intangible
Recreation			Intangible
Total			$49,742

[1] Includes such costs as seeding trails to grass, building headwalls, cleaning logging debris from streams, and closing temporary truck trails to traffic.

[2] Fair market value based on average contract prices from three concurrent Forest Service sales of similar species, log grades, topography, and hauling distance from local mills. Logging costs were furnished by the contractor.

[3] The value of the first year increase in water was estimated at $12 per acre-foot (average cost of irrigation water).

EVALUATING CONFLICTS

We have known for many years that the water yielded by Appalachian uplands can be substantially increased by cutting forest with no loss in quality and some improvement in timing. Furthermore, it has often been suggested that timber, wildlife, and recreation resources can be increased by intensive forest management. Compatibility among these management objectives appears to be increasing for several reasons. The capital investment value of a multiple-purpose access system is being recognized, after many years of planning truck trails merely to extract wood products. The importance of water supplies ***even in the humid east*** is leading to specific recommendation of forest cutting to increase streamflow. Demands for more recreational opportunities are changing public attitudes toward the practice of outdoor recreation. Research indicates an increasing compatibility between wildlife management and silvicultural systems. And there is a recent shift from all-aged selection management in mountain hardwoods to even-aged management which meshes well with the objectives of water yield improvement. All these trends were taken into account in planning this experiment.

A compatible set of uses for the 356-acre watershed appears to be demonstrated. However, it was not the intention of this experiment to say "this is how it ought to be" but rather to afford a preview of how it might be, whether it ought to or not. The physical and biological impacts of intensive management on this small watershed can influence managers and users by helping to clarify what is physically possible and aesthetically desirable in managing mountain forests. The interactions of many tangible and intangible products and uses were partially evaluated previously as impacts on the several resources. But the problem of quantifying the interactions and conflicts among various resources and management practices remains unsolved. Even if economic data were available, and the area large enough to inventory investments and returns systematically, the changing demands on forest resources in the region would reduce prediction to a guessing game. Future management of the watershed must be left to future managers, and this we have done by selecting uses and prescriptions which will not initiate irreversible processes on the area. Thus, we have selected water, timber, wildlife, and recreation, and have implicitly rejected strip mining, agriculture, summer home development, highway construction, and all other uses which would permanently alter land and natural resources. If desirable, closure for 50 years will return the area substantially to its original state, except for the overgrown roadbeds which will be permanently visible in winter. But it is time to sound a somber note—one irreversible process has definitely been set in motion and that is management itself. If management cannot be controlled by policy, this or any watershed is at the mercy of the future.

Some irreversible trends are subtle, and only time and further research will tell whether we have selected and prescribed wisely. For example, will the dense road and trail system encourage so much traffic that soil and stream stability will deteriorate in time? If future managers slip into the habit of widening and proliferating roads in response to increasing traffic, water quality and other values will suffer. As planned, however, the nature of the truck trails, the frequent dips and narrow beds, serve both to provide essential access and to discourage aimless racing about in cars.

Will the quality of plant and animal life, or the beauty of the area, change irreversibly? Again, if the manager maintains adequate control, these values can be restored to any desirable level short of pristine wilderness. By avoiding irreversible prescriptions we have left future managers a high degree of flexibility in ordering or altering uses to accommodate changes in demand.

But what of the conflicts among uses as prescribed? Some qualitative ratings have been made on the basis of comments by visiting specialists, day-to-day observations on the site, and on research results. In table 4, the effect of management practices is rated by pluses, minuses, and zeros, indicating respectively favorable, unfavorable, and no appreciable influence on resources or resource use. No attempt has been made to weigh practices by dollar values, although in the case of timber and water quantity we may soon be able to substitute dollar-per-acre estimates.

Specialists in various management fields may well question these qualitative ratings. In the case of recreation—hunting and fishing excepted—we have received widely conflicting views. Some like openings in an otherwise unbroken forest cover and also favor contour truck trails as varied and interesting walking lanes; others prefer nature undisturbed and the solitudes of full forest cover. There is much to be said for both views. The ratings in table 4 denote some improvement in the quantity of recreation, while the quality is judged to have suffered, at least temporarily. Since users and managers might quarrel endlessly over the structuring, rating, and meaning of table 4, it is presented merely to summarize a mixture of facts, impressions, and opinions regarding one experiment, and at the same time to help clarify points of departure among managers, policy makers, and users of public forests.

Table 4.—*A preliminary qualitative rating of management practices in relation to resource values of the experimental watershed. Plus, minus, and zero imply favorable, unfavorable, and no appreciable effect, respectively*

Management practices	Water		Timber		Wildlife		Recreation		Net influence (sum)
	Quant.	Qual.	Quant.	Qual.	Quant.	Qual.	Quant.	Qual.	
Road construction	+	—	0	0	+	0	+	—	+
Cutting vegetation	+	0	+	+	+	+	0	—	+
Logging operations	0	—	+	+	0	0	0	—	0
Stream improvement	0	—	0	0	?	?	0	0	—

Simply adding up the pluses and minuses suggests that 20 percent of the interactions reflect conflict, while 80 percent reflect complementary or supplementary uses. Only the quality of water and recreation have suffered according to our rating, while stream improvement is the only management activity given no plus rating. The question marks under wildlife denote chiefly the lack of knowledge about the effect of stream improvement on fish. It will not do to overwork the implications of table 4, but certainly the present management scheme would look highly suspicious if the percentages were reversed and interactions among resource and management practices were judged to be 80 percent conflictive.

Protection against fire, insects, disease, flood, and vandalism is not listed under practices because various forms of protection are continuing or emergency activities which are difficult to rate against resource use. None of the activities practiced here on highly permeable soils has much influence on floods except as the term flood is extended to mean on-site damage to roads and small channels. Land use must be much more drastically altered to produce enough overland flow or channel sediment to seriously affect downstream conditions.

Management of this experimental watershed may continue for many years. Its value lies not solely in final results but rather in the impact on those who are now managing the Appalachian forests. How can the methods and plans be improved? Are there ways to reduce the remaining conflicts? Will forest management be this intensive? Or will it be more intensive? If the uses or prescriptions here "mocked up" on a small parcel of scenic mountain land are not acceptable to the public or the manager, what are the alternatives? If multiple use is to be a lasting policy, the questions raised by this type of pilot test must be answered.

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A Drought Index for Forest Fire Control

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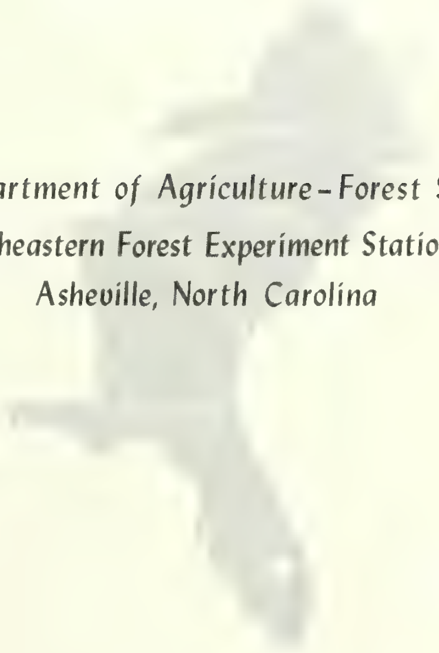

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A Drought Index for Forest Fire Control

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INTRODUCTION

The moisture content of the upper soil, as well as that of the covering layer of duff, has an important effect on the fire suppression effort in forest and wildland areas. In certain forested areas of the United States, fires in deep duff fuels are of particular concern to the fire control manager. When these fuels are dry, fires burn deeply, damage is excessive, and fire extinguishment unduly expensive. Even relatively small fires are costly; the larger fires may be disastrous. As an example, in 1955 and 1956, four fires in the Southeast each burned more than 100,000 acres. During these years, normally moist areas which usually served as good fire barriers, such as branch heads and bays, became so dry that the fires accelerated through the heavy fuel instead of slowing down.

Certainly, factors in addition to soil moisture influenced the occurrence and behavior of these and other less spectacular fires. However, experience over the years has established the close association of extremely difficult fire suppression with cumulative dryness, or drought.

In fire control, the critical effects of drought are not confined to deep organic soils. Dried-out organic materials are frequently imbedded in the shallow upper layers of mineral soils. These fuel pockets can become a deciding factor in whether or not firelines will hold and a further problem in mopup operations. During extreme drought conditions, the moisture content of living brush and tree crowns may be lowered, fires may crown more readily, and some of the woody vegetation may die. Furthermore, the curing of herbaceous material during the growing season is associated with periods of little or no rainfall. It is important to recognize how drought intensifies the problem of fire control.

Drought development, especially in the early stages, is frequently unrecognized and certainly is not uniformly interpreted. The need for a systematic method of estimating the progress of drought has been emphasized by State and Federal fire control officers. This recurring problem stimulated the search for a measure of drought that would be useful in planning fire control operations.

The statement that follows should be considered as a progress report. The physical theory and the general framework for a drought index have been developed, but there are gaps in our knowledge of the precise form of the moisture relationships. We believe, therefore, that the study of drought, both as to measurement and to interpretation, should be continued with increased emphasis.

GENERAL

Drought has been defined in many ways. Palmer (1965) lists seven different definitions of drought which have appeared in past studies and states that the list could be extended. For forest fire control, a useful concept of drought is one which treats it as a continuous quantity which can be described in numerical terms. The values would range from zero (soil and duff saturated with water) up to some maximum value which corresponds to an absence of available moisture in the soil and duff. This point of view does not necessarily emphasize the extreme or unusual aspects of the drought concept. However, the upper part of the scale does correspond to those conditions for which many definitions of drought require that the dryness or moisture deficiency be "abnormal" or "unusual."

As used in this paper, drought index is defined as a number representing the net effect of evapotranspiration and precipitation in producing cumulative moisture deficiency in deep duff or upper soil layers. Drought index is, thus, a quantity that relates to the flammability of organic material in the ground.

The material may be soil humus, in which case the upper soil may appear to burn if fires occur when the index is high. The organic material may also consist of buried wood, such as roots in varying degrees of decay, at different depths below the mineral soil surface. The relative dryness of these fuels is a direct effect of drought and, because of the problem of firelines noted previously, is of greater significance in fire suppression than in fire behavior.

There may, however, be important indirect effects of an extended drought on specific fire behavior characteristics, such as rate of spread or energy release, because these variables are affected by the size of the area on fire at one time. Fires may also crown more readily under drought conditions. A prolonged drought influences fire intensity largely because more fuel is available for combustion. The increased intensity, added to the difficulty of holding firelines, greatly adds to the effort required for fire suppression.

We emphasize that the drought index described in this report is not in any way a substitute for the moisture parameters used in the spread phase of the National Fire Danger Rating System. A drought condition is not a prerequisite for the occurrence and spread of fire in any area. The drought index does not replace the buildup index, because it represents an entirely different moisture regime in which the response to weather changes is much slower than with the buildup index. The purpose of the drought index is to provide fire control managers with a continuous scale of reference for estimating deep-drying conditions in areas where such information may be useful in planning fire control operations.

STRUCTURE OF THE DROUGHT INDEX

The physical theory and the general framework for a drought index that should operate through a wide range of climatic conditions is given in the Appendix. The theory and framework are based on the following assumptions:

1. The rate of moisture loss in a forested area will depend on the density of the vegetation cover in that area. In turn, the density of the vegetation cover, and, consequently, its transpiring capacity, is a function of the mean annual rainfall. Furthermore, the vegetation will eventually adjust itself to use most of the available moisture.

2. The vegetation-rainfall relation is approximated by an exponential curve in which the rate of moisture removal is a function of the mean annual rainfall. Therefore, the rate decreases with decreasing density of vegetation, hence, with decreasing mean annual rainfall.

3. The rate of moisture loss from soil is determined by evapotranspiration relations.

4. The depletion of soil moisture with time is approximated by an exponential curve form in which wilting point moisture[1] is used as the lowest moisture level. Thus, the expected rate of drop in soil moisture to the wilting point, under similar conditions, is directly proportional to the amount of available water in the soil layer at a given time.

5. The depth of the soil layer wherein the drought events occur is such that the soil has a field capacity of 8 inches of available water. Although the selection of 8 inches is somewhat arbitrary, a precise numerical value is not essential. Eight inches of available moisture appears reasonable for use in forest fire control because in many areas of the country it takes all summer for the vegetation cover to transpire that much water.

From these assumptions, plus supporting data, a mathematical description of the overall process was developed (see Appendix). The final equations were then expressed in a form suitable for solution by slide rule or computer.

With the exception of assumption No. 1, the basic principles upon which the drought index is based are similar to those upon which Nelson (1959) based his index. However, he used a linear relationship in assumption No. 4 instead of the exponential form. The precise nature of the soil moisture depletion curve is still in doubt, but most investigators now seem to prefer the exponential form. This question is discussed further in the Appendix.

DROUGHT INDEX COMPUTATIONS

Drought index may be computed for any desired level of mean annual rainfall, but to simplify the computations for field use, five tables of drought factors were made up. Each table covers a specified range of mean annual rainfall. Tables 1 through 5 and a sample recording form (fig. 1) with instructions are included in this section.[2]

The measurements needed for the drought index are (1) the maximum air temperature (or the dry-bulb temperature at time of basic observation) and (2) the total rainfall for the past 24 hours. This information is available at stations that regularly compute spread index.

---

[1] For the purpose of this paper, the wilting point will be defined as that soil moisture content which marks the limit of the zone of available moisture and separates it from the zone of unavailable moisture. If the moisture content is greater than the wilting point moisture, the excess above the wilting point is available for transpiration; if it is below the wilting point, the moisture is not available for transpiration.

[2] The drought factors in tables 1 through 5 were taken from IBM tabulations programed by Marshall P. Waters, University of Georgia Computer Center, Athens, Georgia. Each drought factor value represents a solution of Equation 18 in the Appendix. Factors were computed to tenths, at 3-degree temperature increments, from 51° to 108° F. for mean annual rainfalls of 15 inches (table 1), 25 inches (table 2), 35 inches (table 3), 50 inches (table 4), and 70 inches (table 5). Values read from the IBM tabulations were rounded to the nearest whole number, raising fractions of 0.5 or more to the next higher number.

Table 1.--Drought factors for areas with mean annual rainfall 10 inches to 19 inches.

Temperature [2]	Drought index yesterday (or as reduced by precipitation) [1]															
	0 to 49	50 to 99	100 to 149	150 to 199	200 to 249	250 to 299	300 to 349	350 to 399	400 to 449	450 to 499	500 to 549	550 to 639	640 to 699	700 to 759	760 to 799	800
	- - - - - - - - - - Drought factor - - - - - - - - - -															
107+	21	19	18	17	15	14	13	11	10	9	7	5	3	2	1	0
104-106	18	17	15	14	13	12	11	10	8	7	6	5	3	2	1	0
101-103	15	14	13	12	11	10	9	8	7	6	5	4	2	1	1	0
98-100	13	12	11	11	10	9	8	7	6	5	5	3	2	1	1	0
95-97	11	10	10	9	8	8	7	6	5	5	4	3	2	1	1	0
92-94	9	9	8	8	7	6	6	5	5	4	3	3	2	1	0	0
89-91	8	8	7	7	6	5	5	4	4	3	3	2	1	1	0	0
86-88	7	6	6	6	5	5	4	4	3	3	2	2	1	1	0	0
83-85	6	5	5	5	4	4	4	3	3	2	2	2	1	1	0	0
80-82	5	5	4	4	4	3	3	3	2	2	2	1	1	1	0	0
77-79	4	4	4	3	3	3	3	2	2	2	1	1	1	1	0	0
74-76	3	3	3	3	3	2	2	2	2	1	1	1	1	1	0	0
71-73	3	3	2	2	2	2	2	2	1	1	1	1	1	1	0	0
68-70	2	2	2	2	2	2	1	1	1	1	1	1	1	0	0	0
65-67	2	2	2	2	1	1	1	1	1	1	1	1	1	0	0	0
62-64	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
59-61	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
56-58	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
53-55	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
50-52	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0

[1] Drought index is reduced one point for each one-hundredth inch of net rainfall--refer to instructions in text.

[2] Dry-bulb temperature (degrees F.) today, at time of basic observation, or use maximum temperature.

Table 2.--Drought factors for areas with mean annual rainfall 20 inches to 29 inches.

Temperature 2/	Drought index yesterday (or as reduced by precipitation) 1/															
	0 to 49	50 to 99	100 to 149	150 to 199	200 to 249	250 to 299	300 to 349	350 to 399	400 to 449	450 to 499	500 to 549	550 to 639	640 to 699	700 to 759	760 to 799	800
	Drought factor															
107+	30	28	26	24	22	20	18	16	14	12	11	8	5	3	1	0
104-106	25	24	22	20	19	17	16	14	12	11	9	7	4	2	1	0
101-103	22	20	19	18	16	15	13	12	11	9	8	6	3	2	1	0
98-100	19	17	16	15	14	13	11	10	9	8	7	5	3	2	1	0
95-97	16	15	14	13	12	11	10	9	8	7	6	4	3	1	1	0
92-94	14	13	12	11	10	9	8	7	7	6	5	4	2	1	1	0
89-91	12	11	10	9	9	8	7	6	6	5	4	3	2	1	1	0
86-88	10	9	9	8	7	7	6	5	5	4	4	3	2	1	1	0
83-85	8	8	7	7	6	6	5	5	4	4	3	2	1	1	0	0
80-82	7	7	6	6	5	5	4	4	3	3	3	2	1	1	0	0
77-79	6	5	5	5	4	4	4	3	3	2	2	2	1	1	0	0
74-76	5	5	4	4	4	3	3	3	2	2	2	1	1	1	0	0
71-73	4	4	4	3	3	3	2	2	2	2	1	1	1	1	0	0
68-70	3	3	3	3	2	2	2	2	2	1	1	1	1	1	0	0
65-67	3	3	2	2	2	2	2	1	1	1	1	1	1	0	0	0
62-64	2	2	2	2	2	1	1	1	1	1	1	1	1	0	0	0
59-61	2	2	1	1	1	1	1	1	1	1	1	1	0	0	0	0
56-58	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
53-55	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
50-52	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0

1/ Drought index is reduced one point for each one-hundredth inch of net rainfall--refer to instructions in text.

2/ Dry-bulb temperature (degrees F.) today, at time of basic observation, or use maximum temperature.

Table 3.--Drought factors for areas with mean annual rainfall 30 inches to 39 inches.

Temperature 2/	Drought index yesterday (or as reduced by precipitation) 1/															
	0 to 49	50 to 99	100 to 149	150 to 199	200 to 249	250 to 299	300 to 349	350 to 399	400 to 449	450 to 499	500 to 549	550 to 639	640 to 699	700 to 759	760 to 799	800
	Drought factor															
107+	41	38	36	33	30	28	25	23	20	17	15	11	6	4	1	0
104-106	35	33	31	28	26	24	22	19	17	15	13	9	5	3	1	0
101-103	30	28	26	24	22	20	19	17	15	13	11	8	5	3	1	0
98-100	26	24	23	21	19	18	16	14	13	11	9	7	4	2	1	0
95-97	22	21	19	18	16	15	14	12	11	9	8	6	3	2	1	0
92-94	19	18	16	15	14	13	12	10	9	8	7	5	3	2	1	0
89-91	16	15	14	13	12	11	10	9	8	7	6	4	3	1	1	0
86-88	14	13	12	11	10	9	8	7	7	6	5	4	2	1	1	0
83-85	11	11	10	9	9	8	7	6	6	5	4	3	2	1	1	0
80-82	10	9	8	8	7	7	6	5	5	4	3	3	2	1	0	0
77-79	8	8	7	7	6	6	5	4	4	3	3	2	1	1	0	0
74-76	7	6	6	5	5	5	4	4	3	3	2	2	1	1	0	0
71-73	6	5	5	5	4	4	3	3	3	2	2	2	1	1	0	0
68-70	5	4	4	4	3	3	3	3	2	2	2	1	1	1	0	0
65-67	4	3	3	3	3	3	2	2	2	2	1	1	1	1	0	0
62-64	3	3	3	2	2	2	2	2	1	1	1	1	1	1	0	0
59-61	2	2	2	2	2	2	1	1	1	1	1	1	1	0	0	0
56-58	2	2	2	1	1	1	1	1	1	1	1	1	1	0	0	0
53-55	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
50-52	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0

1/ Drought index is reduced one point for each one-hundredth inch of net rainfall--refer to instructions in text.

2/ Dry-bulb temperature (degrees F.) today, at time of basic observation, or use maximum temperature.

Table 4.--Drought factors for areas with mean annual rainfall 40 inches to 59 inches.

Temperature 2/	Drought index yesterday (or as reduced by precipitation) 1/															
	0 to 49	50 to 99	100 to 149	150 to 199	200 to 249	250 to 299	300 to 349	350 to 399	400 to 449	450 to 499	500 to 549	550 to 639	640 to 699	700 to 759	760 to 799	800
	Drought factor															
107+	62	58	54	50	46	42	38	34	30	26	22	16	10	6	2	0
104-106	53	50	46	43	39	36	33	29	26	22	19	14	8	5	1	0
101-103	46	43	40	37	34	31	28	25	22	19	16	12	7	4	1	0
98-100	39	37	34	31	29	26	24	21	19	16	14	10	6	4	1	0
95-97	33	31	29	27	25	23	20	18	16	14	12	9	5	3	1	0
92-94	28	27	25	23	21	19	17	16	14	12	10	8	4	3	1	0
89-91	24	23	21	20	18	16	15	13	12	10	9	6	4	2	1	0
86-88	21	19	18	17	15	14	13	11	10	9	7	5	3	2	1	0
83-85	17	16	15	14	13	12	11	10	8	7	6	5	3	2	1	0
80-82	15	14	13	12	11	10	9	8	7	6	5	4	2	1	1	0
77-79	12	11	11	10	9	8	8	7	6	5	4	3	2	1	1	0
74-76	10	10	9	8	8	7	6	6	5	4	4	3	2	1	1	0
71-73	8	8	7	7	6	6	5	5	4	4	3	2	1	1	0	0
68-70	7	6	6	6	5	5	4	4	3	3	2	2	1	1	0	0
65-67	6	5	5	4	4	4	3	3	3	2	2	2	1	1	0	0
62-64	4	4	4	4	3	3	3	2	2	2	2	1	1	1	0	0
59-61	3	3	3	3	3	2	2	2	2	1	1	1	1	1	0	0
56-58	3	2	2	2	2	2	2	1	1	1	1	1	1	0	0	0
53-55	2	2	2	1	1	1	1	1	1	1	1	1	1	0	0	0
50-52	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0

1/ Drought index is reduced one point for each one-hundredth inch of net rainfall--refer to instructions in text.

2/ Dry-bulb temperature (degrees F.) today, at time of basic observation, or use maximum temperature.

Table 5.--Drought factors for areas with mean annual rainfall 60 inches or more.

Temperature [2]	Drought index yesterday (or as reduced by precipitation) [1]															
	0 to 49	50 to 99	100 to 149	150 to 199	200 to 249	250 to 299	300 to 349	350 to 399	400 to 449	450 to 499	500 to 549	550 to 639	640 to 699	700 to 759	760 to 799	800
	Drought factor															
107+	91	85	79	73	68	62	56	50	44	38	32	24	14	8	2	0
104-106	78	73	68	63	58	53	48	43	38	33	28	21	12	7	2	0
101-103	67	63	58	54	50	45	41	37	32	28	24	18	10	6	2	0
98-100	57	54	50	46	43	39	35	31	28	24	20	15	9	5	2	0
95-97	49	46	43	40	36	33	30	27	24	21	17	13	8	4	1	0
92-94	42	39	36	34	31	28	26	23	20	18	15	11	7	4	1	0
89-91	36	33	31	29	26	24	22	19	17	15	13	9	6	3	1	0
86-88	30	28	26	24	22	20	18	17	15	13	11	8	5	3	1	0
83-85	25	24	22	21	19	17	16	14	12	11	9	7	4	2	1	0
80-82	21	20	19	17	16	15	13	12	10	9	8	6	3	2	1	0
77-79	18	17	16	14	13	12	11	10	9	8	6	5	3	2	1	0
74-76	15	14	13	12	11	10	9	8	7	6	5	4	2	1	1	0
71-73	12	12	11	10	9	8	8	7	6	5	4	3	2	1	1	0
68-70	10	9	9	8	7	7	6	6	5	4	4	3	2	1	1	0
65-67	8	8	7	7	6	6	5	4	4	3	3	2	1	1	0	0
62-64	6	6	6	5	5	4	4	4	3	3	2	2	1	1	0	0
59-61	5	5	4	4	4	3	3	3	2	2	2	1	1	1	0	0
56-58	4	4	3	3	3	3	2	2	2	2	1	1	1	1	0	0
53-55	3	2	2	2	2	2	2	1	1	1	1	1	1	0	0	0
50-52	2	2	2	1	1	1	1	1	1	1	1	1	1	0	0	0

[1] Drought index is reduced one point for each one-hundredth inch of net rainfall--refer to instructions in text.

[2] Dry-bulb temperature (degrees F.) today, at time of basic observation, or use maximum temperature.

Only one drought factor table is needed at any selected station. Thus, to compute drought index it is first essential to decide which drought factor table to use. The appropriate table is determined by the long-term mean annual rainfall of the area. Because the range of mean annual rainfall in each table is fairly broad, a reliable estimate applicable to the rating area can usually be obtained from the nearest U. S. Weather Bureau office.

In remote areas it may be necessary to refer to state maps which show lines of mean annual rainfall drawn through points of approximately equal value (called isohyets). These maps are available in the publication, "Climates of the States," which is prepared by the U. S. Weather Bureau and issued separately for each state. Caution should be used in interpolating between the lines on these maps, particularly in mountainous areas.

Starting a Drought Index Record

An examination of the drought factor tables makes it clear that, for any given temperature, the drought factor to be added each day depends on the drought index yesterday. This cumulative feature means that an observer starting a drought index record cannot automatically begin at zero. The zero point may have occurred weeks or months before, or even during the previous year. It is necessary to go back in time until a day is reached on which it is reasonably certain that the upper soil layers were saturated, then bring the record forward day by day to the starting date. In areas of heavy snowfall, it is normally safe to assume saturation just after the snow melts in the spring. When starting a record in snowfree areas, it is necessary to go back to a period of abundant rainfall, such as 6 or 8 inches in a period of a week. The index must be very low, if not actually zero, at the end of the rainy period.

When the starting point has been determined and the proper drought factor table has been selected, the computation of drought index each day is a simple bookkeeping procedure. Essentially, there are two steps:

Step 1--Reduce the drought index by the amount of net rain, if any.

Step 2--Increase the drought index by the amount found in the drought factor table.

The mechanics are explained in the next subsection. (For simplicity of use in the field, the following instructions are presented in an abbreviated style.)

Instructions for Computing Drought Index (refer to sample record, fig. 1)

Column 2--24-Hour Rainfall

Record measured amount of rain to nearest 0.01 inch. Follow standard instructions for melted snow and recording the water equivalent.

sample	sample	sample	June	1966
Agency	District	Station	Month	Year

Day of the Month	24-Hour Rainfall (measured amount)	Net Rainfall (adjusted amount--see instructions)	Air Temperature ☒ maximum temp. ☐ dry-bulb temp.	Drought Index yesterday, or as reduced by net rainfall (col. 3)	Drought Factor From Table 4	Drought Index For Today col. 5 plus col. 6	Current Stage of Drought
1	2	3	4	5	6	7	8
1		0	79	164	10	174	1
2		0	75	174	8	182	1
3	0.66	.46	70	136	6	142	1
4	T	0	76	142	9	151	1
5	0.23	.03	79	148	11	159	1
6		0	84	159	14	173	1
7	0.16	0	65	173	4	177	1
8	0.09	.05	66	172	4	176	1
9		0	83	176	14	190	1
10		0	70	190	6	196	1
11	0.08	0	67	196	4	200	2
12	0.03	0	65	200	4	204	2
13		0	76	204	8	212	2
14	0.22	.02	69	210	5	215	2
15		0	65	215	4	219	2
16	0.21	.01	75	218	8	226	2
17		0	78	226	9	235	2
18		0	85	235	13	248	2
19		0	88	248	15	263	2
20	0.01	0	79	263	8	271	2
21		0	69	271	5	276	2
22		0	75	276	7	283	2
23		0	84	283	12	295	2
24		0	89	295	16	311	3
25		0	93	311	17	328	3
26		0	92	328	17	345	3
27		0	96	345	20	365	3
28		0	91	365	13	378	3
29	0.25	.05	78	373	7	380	3
30	0.16	.16	83	364	10	374	3
31							

Figure 1.--Drought index sample record.

Column 3--Net Rainfall

Subtract 0.20 from amount in column 2 to obtain net rainfall. Record 0 (zero) if amount in column 2 is 0.20, or less.

Exception: If there are CONSECUTIVE rainy days, with no drying of tree canopy between showers, subtract only once, on the day that the cumulative rainfall exceeds 0.20. Thereafter, consider all of the rain in column 2 as net rainfall (and transfer the amount to column 3) until the wet spell ends. Consider wet spell ended on first 24-hour period with no measurable rain. In case of snow--consider no drying as long as snow blankets the fuels, and transfer all measured water equivalent to column 3.

Example 1--0.20 was subtracted from each of the individual rains on June 3, 5, 14, and 16. (See sample record, fig. 1.)

Example 2--Rains on June 7-8 were consecutive, so the 0.20 was subtracted when total rain exceeded 0.20, which was June 8.

Example 3--Rains on June 29-30 were consecutive, so 0.20 was subtracted on first day, and all of the rain was transferred to column 3 on second day.

Column 4--Air Temperature

Record air temperature to nearest degree, rounding fractions of 0.5 or more to next higher number. Place an "x" in appropriate box at head of column to identify the temperature used--whether maximum for the day, or dry-bulb temperature at time of basic observation.

Column 5--Drought Index yesterday, or as reduced by net rainfall in column 3

During rainless periods, or when net rainfall in column 3 is zero, enter in column 5 the drought index recorded in column 7 on the previous day. When there is net rainfall in column 3, subtract the number of hundredths inches of rain from the previous day's drought index, and record the reduced drought index in column 5.

Example 1--No net rain on June 2. Drought index was 174 (column 7) on June 1. Therefore, 174 was carried forward to column 5 for June 2.

Example 2--Net rain on June 3 was 46 hundredths. Drought index June 2 was 182 (column 7). Therefore, 182 minus 46 equals 136, the number to record in column 5 for June 3.

Column 6--Drought Factor

Use the appropriate Drought Factor Table as determined by the mean annual rainfall of the rating area. If your area has a mean annual rainfall that seems to fall right on the borderline between tables, such as 19.50 inches or 39.50 inches, use the table with the next higher number. Insert the table number used in the box provided at the top of column 6.

Procedure--refer to Temperature in column 4 and Drought Index yesterday in column 5. Record the drought factor where these numbers intersect in Drought Factor Table.

Example: For June 10, Temperature 70 and Drought Index yesterday 190 intersect at drought factor 6 in table 4.

Column 7--Drought Index For Today

Add Drought Index yesterday in column 5 to drought factor in column 6 to obtain Drought Index For Today.

Example: For June 10, 190 plus 6 equals 196.

Column 8--Current Stage of Drought

Refer to Drought Index For Today in column 7, and determine the drought stage as follows:

Index	Stage	Index	Stage
0-99	0	400-499	4
100-199	1	500-599	5
200-299	2	600-699	6
300-399	3	700-800	7

Example: The Drought Index For Today on June 10 is 196 (column 7), so the drought stage is 1.

DROUGHT INDEX INTERPRETATION

Because the drought index number expresses moisture deficiency in hundredths of an inch and the index is based on 8.00 inches of water available for transpiration, the index is on a scale ranging from 0 to 800. Zero is the point of no moisture deficiency and 800 is the maximum drought that is possible. At any point along the scale, the index number indicates the amount of net rainfall (in hundredths) that is required to reduce the index to zero, or saturation.

To facilitate the description and to clarify the discussion of drought, the available range of drought has been divided into stages. The zero or incipient stage includes the range from 0 to 99, the first stage from 100 to 199, the second stage from 200 to 299, and so on through the seventh stage from 700 to 800 (see instructions above).

Mathematically, the 800 point would require infinite time and, therefore, would never be reached. But by using the rounded off values as set up in the drought factor tables, it is possible to reach 800. Once reached, this maximum cannot be exceeded, because the drought increment at index 800 is zero.

Although the drought index number has a definite meaning in terms of moisture deficiency, the significance of a particular stage of drought for fire control must be determined locally. As a part of the exploratory study of this index, we have examined weather records from several climatic regimes extending from Alaska to Florida and including a wide range of mean annual rainfall. The results of a few of these analyses are discussed in this report to give the reader a clearer understanding of the drought stages and their implication for fire control. Certainly, they are not a substitute for local studies aimed at the same purpose.

In relating drought index to specific locations, we must select the proper drought factor table. This selection is determined by the mean annual rainfall of the area. One simple way to emphasize the importance of selecting the proper table is to compute, according to each of the five tables, the number of consecutive days having a constant maximum temperature and no effective rainfall that must elapse (after starting at zero) before a selected stage of drought is reached. The following tabulation lists the number of days required, according to each of the tables, to reach the fifth stage (500) when the observed temperature each day ranges from 80° to 82° F.:

Table number	Mean annual rainfall	Consecutive drying days needed to reach D. I. 500
	(Inches)	(Number)
1	10-19	157
2	20-29	109
3	30-39	78
4	40-59	52
5	60 or more	36

From the foregoing, we can visualize the two extremes represented by the drought factor tables. If the two areas represented by table 1 and table 5 both started with zero drought index on May 31, then the area with heavy rainfall (table 5) would reach stage 5 in 36 consecutive days, by July 6, and the area of light rainfall (table 1) would reach stage 5 in 157 consecutive days, by November 4.

In a normal or average year the drought index has a definite trend or cycle of values throughout the year with which the index at any time during a given year can be compared. Such a drought index trend (based on 10 years of record) is shown in figure 2 for the airport at Asheville, North Carolina. In the Asheville area, the normal drought index climbs rapidly during June and July, peaks in mid-September, and drops nearly to zero by late February or March. It was found that the normal cycle of drought is well understood by fire control people, both State and Federal, and is reflected in fire control action.

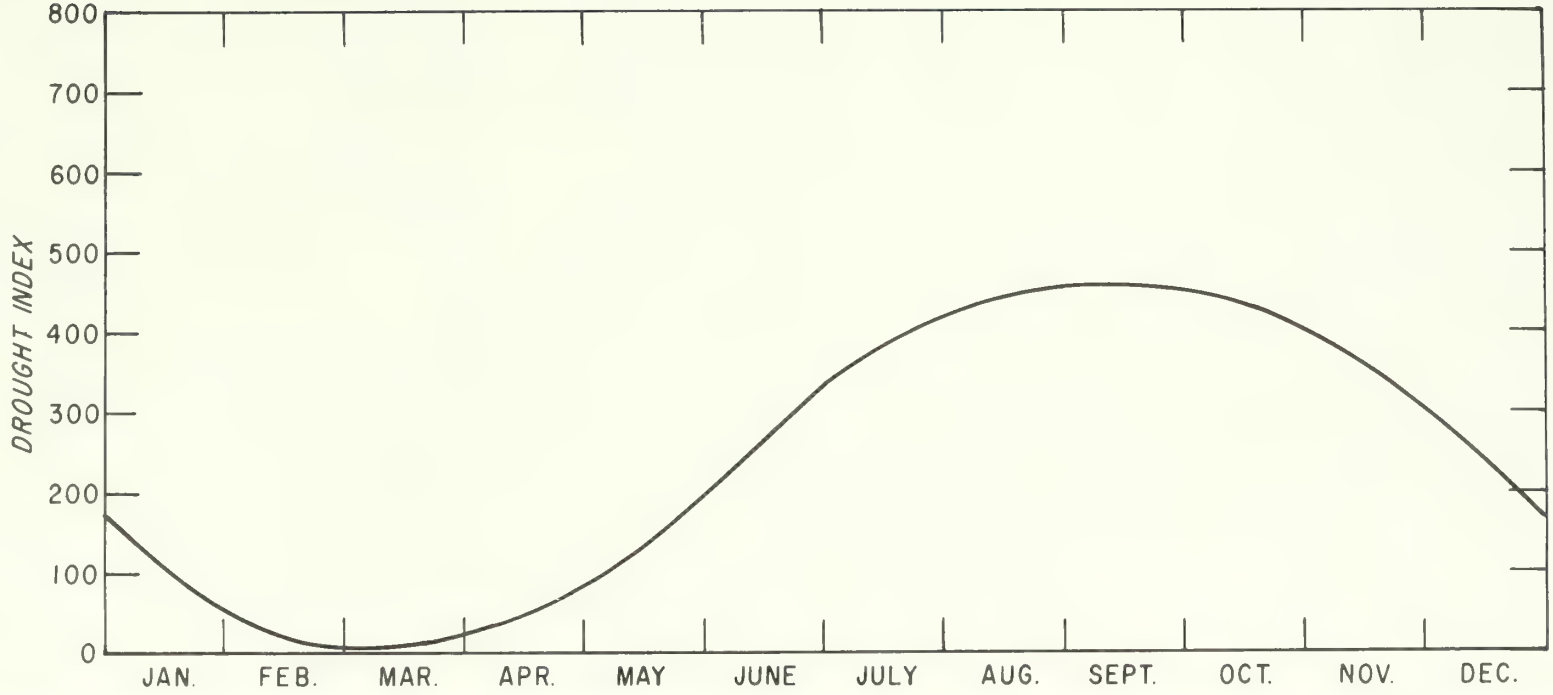


Figure 2.--Annual trend of drought index for the airport at Asheville, North Carolina. (Based on weather records for the period 1951-60.) Mean annual rainfall 48.15 inches.

Because of higher temperatures and more wind, the spring fires in the Asheville district spread faster, on the average, than those in the fall. But once the average spring fire is stopped, mopup is relatively easy. This is not the case in the fall. The typical fall fire burns in cooler weather; there is less wind, and the rate of spread is less than in the spring. Fall fires are therefore easier to stop. But they burn deeper, firelines are more difficult to build and maintain, and mopup is often an extended operation. This activity ties up supervision and manpower and will wear down the organization if fire occurrence continues. When the drought index climbs into the fifth and sixth stages, as it did in 1951, 1952, and 1953, the extinguishment problem is greatly aggravated. In contrast, during the fall of 1959 the index dropped to stage 1 and remained there through the fall season, and firelines were easy to hold.

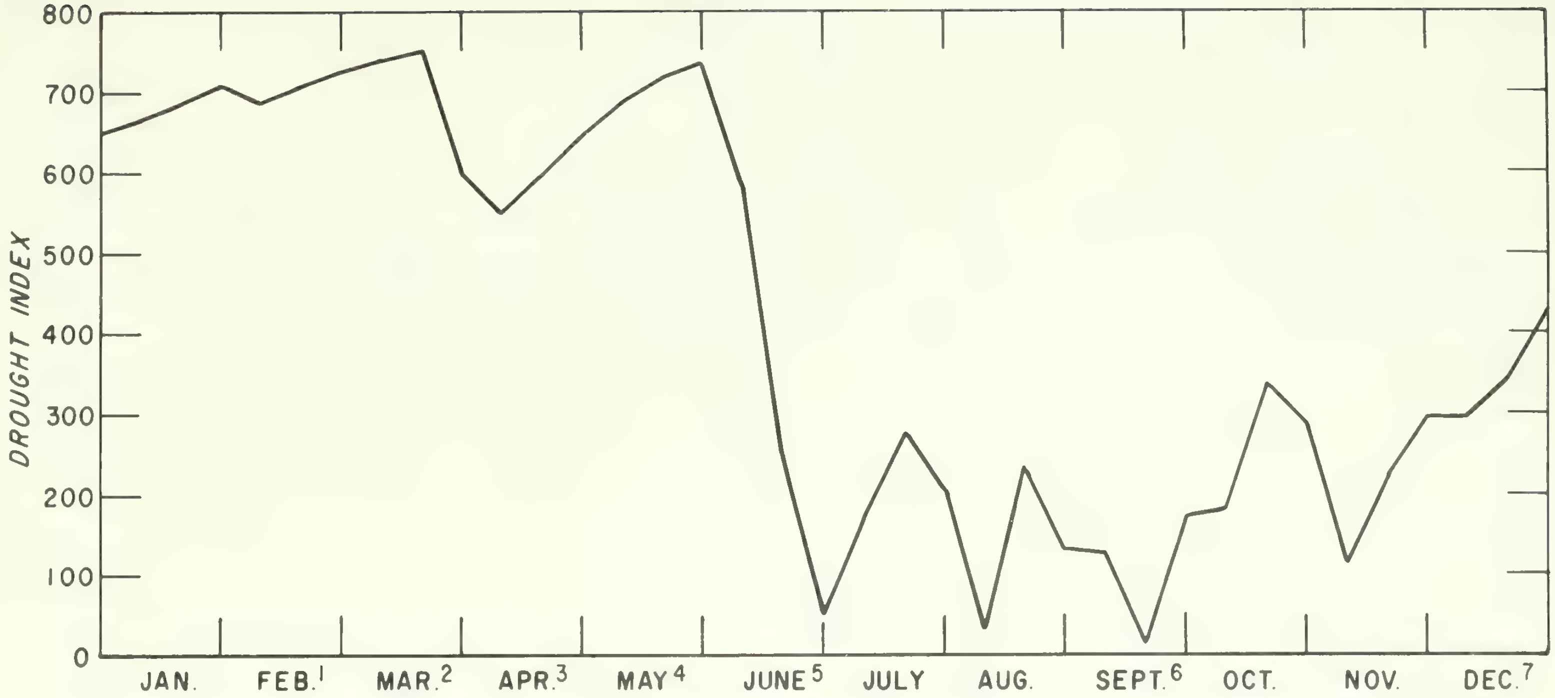
The information on drought index in figures 3 through 6, derived from reports of Monthly Local Climatological Data, gives further information on drought in several parts of the country. Figure 3 depicts the unusually severe drought that persisted near Fort Myers, Florida, during the first 5 months of 1962. From footnote 1 of figure 3, we learn that the drought started in September 1961. Going back to the records for that month, we find that the drought index was in the incipient stage (below 100) at the beginning of September, reached stage 3 on September 20, and edged into stage 4 by the end of the month. This progress seems to agree with the observations quoted in footnote 1.

Ketchikan, Alaska, where the mean annual rainfall is 151.93 inches, is one of the relatively few areas in the country to which table 5 is applicable. In this area of abundant and normally well-distributed rainfall, a drought beyond the incipient stage is unusual. The lowest mean monthly rainfall is 7.34 in June. In the period from 1956 through 1960, 92 percent of the days rated below 100. However, a drought can build up beyond stage 3 in a 30-day summer period with little rain. In 1958, the drought index exceeded 300 from June 20 through July 20 and in the last 3 days of the period was above 500, as is depicted in figure 4.

The opposite end of the climatic scale is represented by Burbank, California, in figure 5. Long rainless periods are a normal event in an area where the mean annual rainfall is only 13.88 inches. With so little rain, one might suspect that there would be relatively small change in the seasonal level of drought; and the drought index for 1961 seems to bear out this supposition. At the beginning of 1961, the area was in the fifth stage. The seriousness of the drought situation was noted by the local unit of the U. S. Weather Bureau (see the note to figure 5 for January 1961).

The moisture deficiency continued to climb throughout the dry summer, reaching a maximum in October well into the seventh stage. The lowest drought index recorded on any day in 1961 was 413, the highest was 743.

However, in going through the Burbank weather records from 1956 until they were discontinued in 1966, we found that 1961 was not a typical year. In fact, it was the most persistently dry year in the 11-year period



Footnotes are based on excerpts from reports of Monthly Local Climatological Data prepared by the U. S. Weather Bureau.

[1] Drought conditions, which began in September 1961, continued through February.

[2] The first 3 weeks of March were dry. The continuing drought of the past several months was relieved somewhat by heavy rains (1.91 in.) on the 25th and 26th.

[3] Drought conditions of the past winter, temporarily relieved during the last week of March and the first week of April, resumed during the last 3 weeks of April.

[4] Smoke and haze from forest fires to the southeast were prevalent during much of the month. This was the driest May of record, also the driest September-May of record.

[5] The 9-month drought was broken by June rains. (Total June rainfall was 12.08 in.)

[6] Temperatures were above normal from June through September. Heavy rains on September 20 and 21 washed out some early planted vegetable crops.

[7] The first half of October was abnormally warm, but November was unusually cool. Warmer weather returned in December. December rain was below normal--the end of December was unusually dry.

Figure 3.--Drought index by 10-day intervals for Fort Myers, Florida, in 1962. Mean annual rainfall 53.27 inches.

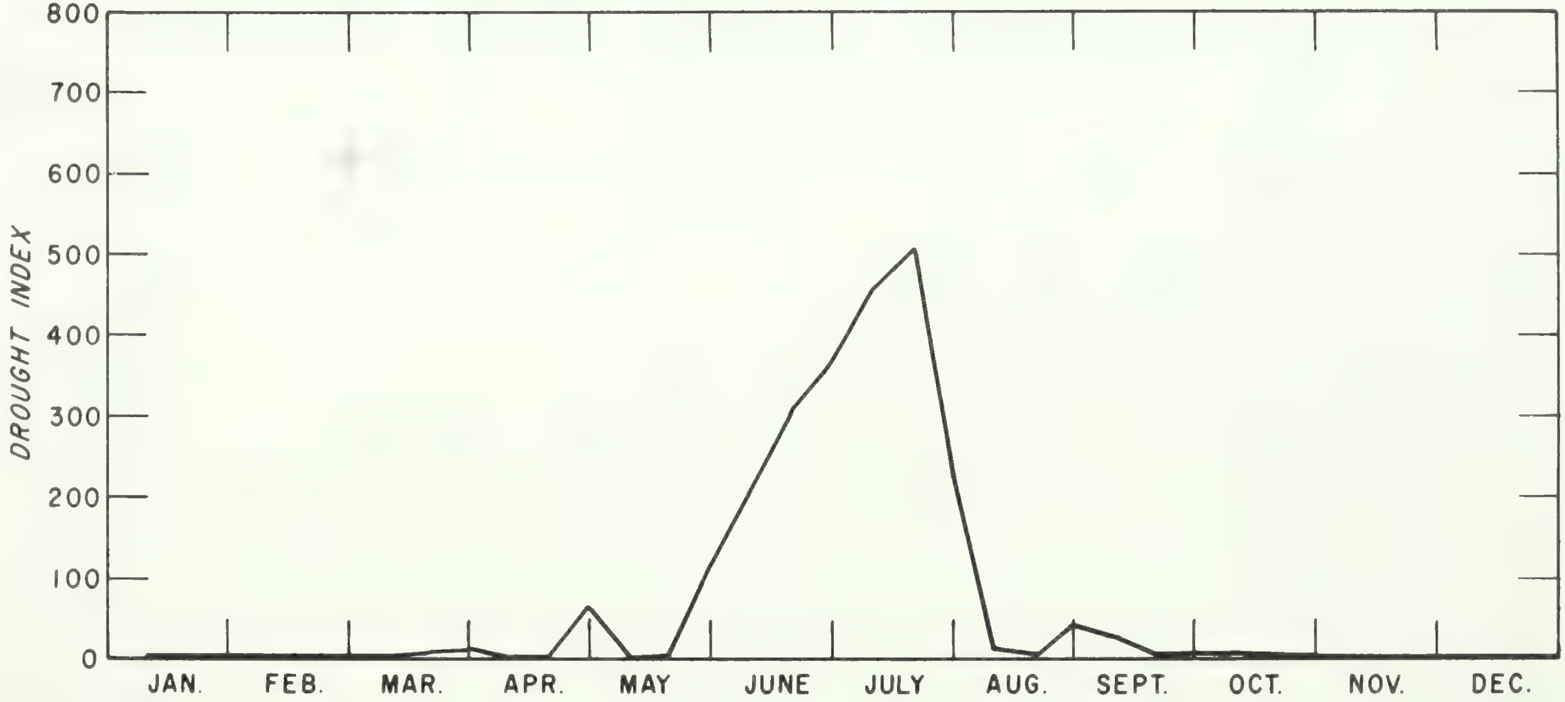
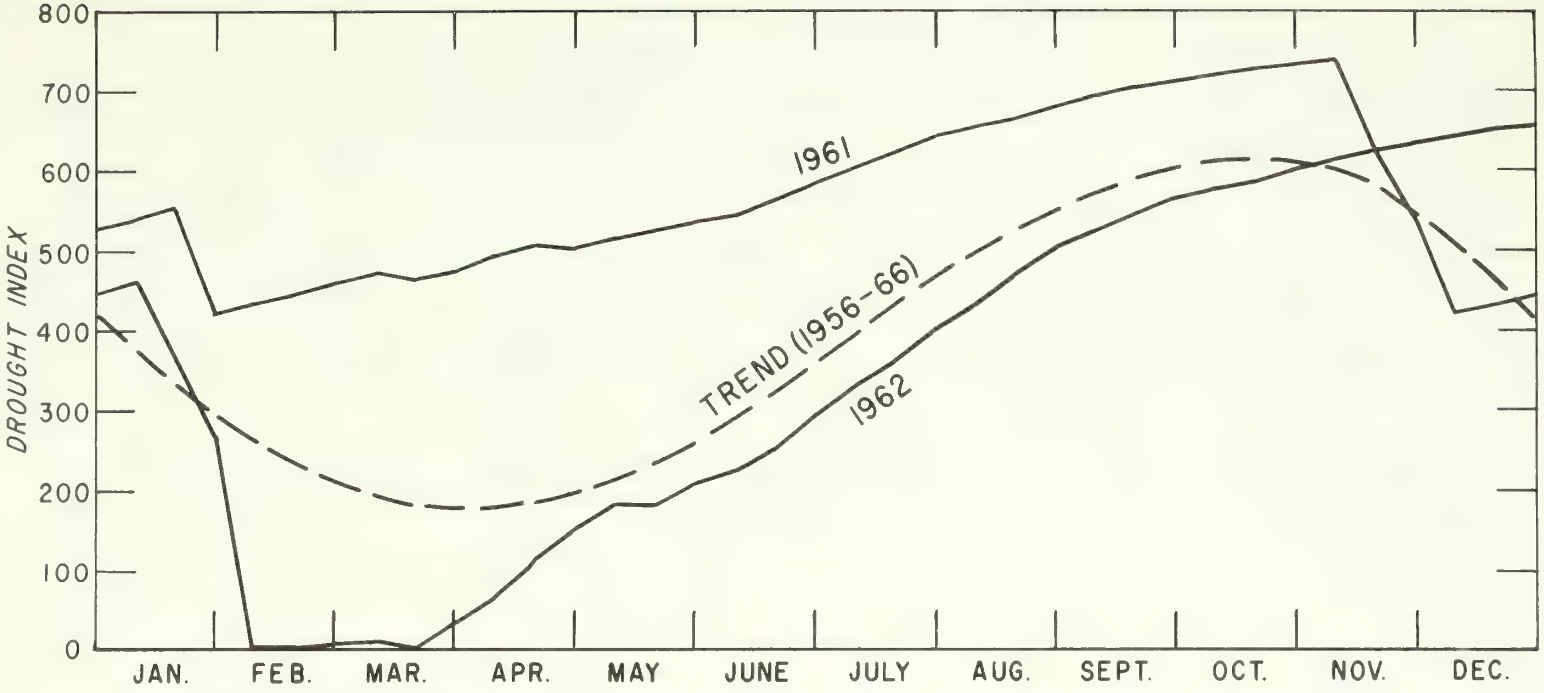


Figure 4.--Drought index by 10-day intervals for Ketchikan, Alaska, in 1958. Mean annual rainfall 151.93 inches.



Notes based on excerpts from reports of Monthly Local Climatological Data prepared by the U. S. Weather Bureau.

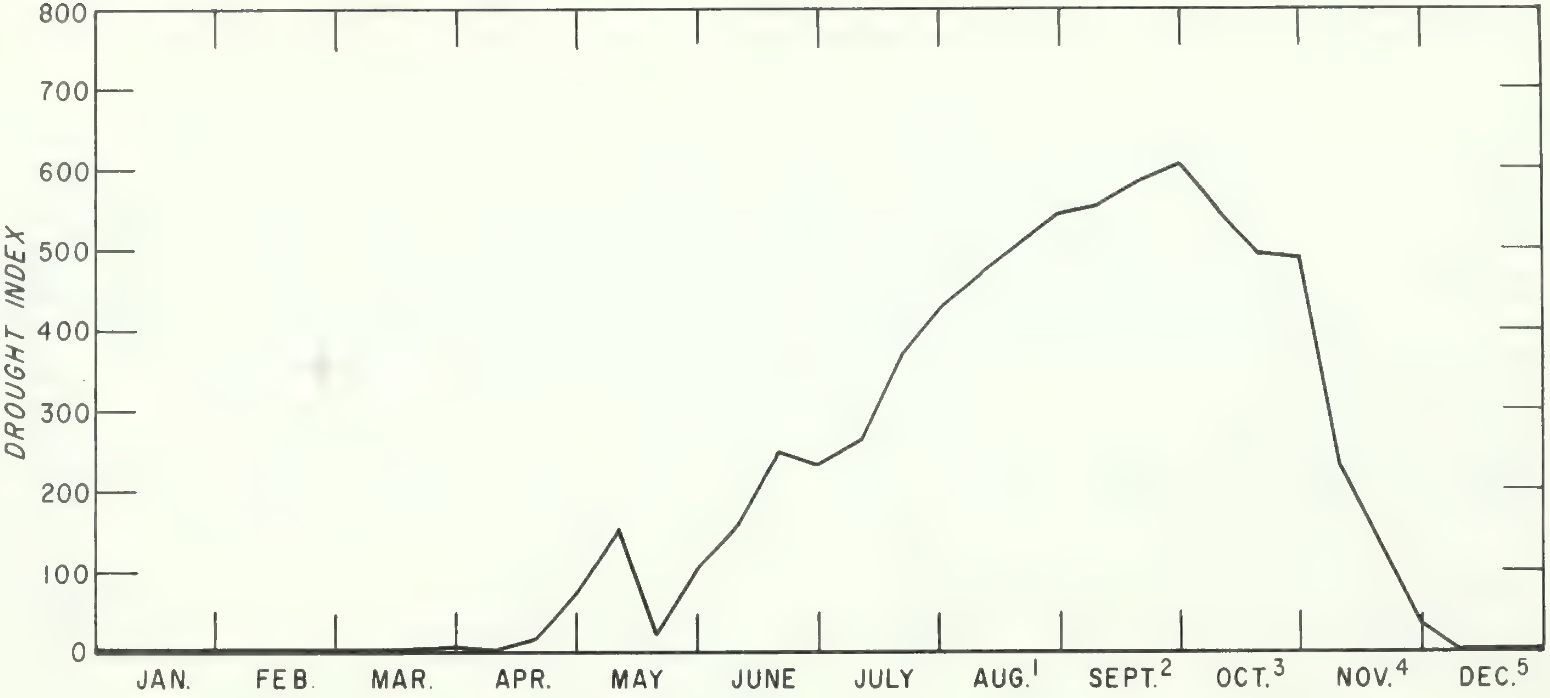
1961

January--The warmest of record. The serious drought situation was eased by substantial rains (1.64 in.) on the 25th and 26th.
April--The fifth consecutive month having below-normal rainfall (now 45 percent of normal) and above-normal temperatures.
June--The precipitation season was the driest of record; only 23.43 in. of precipitation has fallen in the past three precipitation seasons.
October--Only 0.30 in. of rain has fallen since June. Drought is at a maximum.
November--Substantial rains after the 19th (2.70 in.) greatly moderated the severe fire hazard.

1962

February--The wettest February of record (13.30 in.)--seasonal precipitation is 9.62 in. above normal. Rains caused damage from flooding and silting.
June--The driest April of record; the coolest March, May, and June in 10 years.
December--Total precipitation since June was 0.04 in., the lowest ever recorded and 4.53 in. below normal.

Figure 5.--Drought index by 10-day intervals for Burbank, California, in 1961 and 1962. Mean annual rainfall 13.88 inches.



Footnotes based on excerpts from reports of Monthly Local Climatological Data prepared by the U. S. Weather Bureau.

[1] August--The coolest August since 1927, but also the driest since the record-setting August drought of 1947. This month is the eighth in a row with subnormal precipitation.

[2] September--The accumulated drought has dried out many wells and brought about a shortage of water for power generation. There is a potentially dangerous threat of forest fires this fall unless rains in October alleviate the situation.

[3] October--Fortunately, rainy periods were well distributed (although below normal in amount); and the fire hazard that had threatened at the beginning of the month was reduced.

[4] November--Copious precipitation was well spaced throughout the month. The total (5.85 in.) amounted to 35 percent above normal.

[5] December--Rivers rose sharply to normal in December, but no flooding occurred.

Figure 6.--Drought index by 10-day intervals for Portland, Maine, in 1957. Mean annual rainfall 41.78 inches.

and averaged the highest drought index. We found further that zero drought index occurred in one or more of the spring months in 6 of the 11 years. The trend of drought in the Burbank area according to the 1956-66 average is represented by the dashed line in figure 5. In an average year the low point in the drought curve descends into stage 1 in March and April. Thereafter, the index climbs steadily for the next 6 months, peaking just into stage 6 in October.

The 1962 drought, a more typical situation than that in 1961, is represented by the lower line in figure 5. Substantial rains in February brought the index all the way back to zero. Thereafter, the index climbed slowly back to stage 5 at the end of August and into stage 6 by October 31.

A difference in the drought index curves of the magnitude depicted in figure 5 for 1961 and 1962 indicates that soil moisture during the first 10 months of 1961 was markedly lower than for the corresponding months in 1962, at the Burbank station. Additional measurements from several surrounding stations would be needed to determine whether the observed difference in the 1961-62 drought index was localized or was representative of an extensive area.

An interesting comparison can be made, however, with moisture measurements of plant foliage that were taken on the nearby Angeles National Forest. The moisture content of chamise foliage on study plots in the Angeles National Forest has been reported by the Pacific Southwest Forest and Range Experiment Station. These data are contained in a series of 10-day reports on California Fire Weather. A report covering the period from April 10 to October 20 shows the percent moisture content of chamise foliage in 1961 and 1962. The moisture content of the foliage during the period from April to October varied greatly from 1961 to 1962; the distinction was similar to the difference in drought index from 1961 to 1962 shown in figure 5. In 1962 the lowest moisture content reached by October was about 75 percent (at which time the drought index was in the fifth stage). In 1961 the moisture content reached the 75-percent level in May (when the drought index was in the fifth stage) and then dropped to less than 30 percent in October (when the drought index was in stage 7).

A drought in the opposite corner of the country is depicted in figure 6 for Portland, Maine, in 1957. Starting from stage 1 in June, the drought had reached the sixth stage by late September. As the footnote for September indicates, a water shortage was evident at that time. Copious precipitation in the latter part of October and through mid-December (9.49 inches) brought the drought index back to zero. It is probable that the September drought was indeed over by December, because, as the footnote for December indicates, the rivers rose sharply to normal during that month.

SUMMARY AND DISCUSSION

A drought index based on 8 inches of available moisture and the accompanying computational procedures have been discussed. The drought increment on a given day, called the drought factor, is determined by

(1) the mean annual rainfall for the area, (2) the drought index yesterday, and (3) the maximum temperature for today. Reduction in drought occurs only when the 24-hour rainfall exceeds 0.20 inch (called net rainfall). A sample recording form with instructions is included.

Drought development in five areas of the country is illustrated graphically in figures 2 through 6. Selected comments from reports of Local Climatological Data by the U. S. Weather Bureau supplement the graphical record. From this information and other pertinent material assembled for this preliminary study of drought, the following general conclusions seem reasonable:

1. Drought development occurs only during extended periods of little or no rainfall, when the daily maximum temperature is 50° F. or higher.

2. Consistently high daily temperatures, averaging more than 70° F., are required for the development of an appreciable drought, starting from saturation. Because of this requirement, the opportunities for drought development are mainly limited to the period June-September in states along the Canadian border. The period lengthens to March-November in the southern tier of states from Florida westward.

3. Some degree of summer drought is normal in most areas of the country. This development has variable significance, depending upon the stage that is reached and whether or not deep duff fuels are present in the rating area.

In deep duff fuels, characteristic, for example, of the spruce-fir region of the Northeast, trouble with deep-burning summer fires (in the local vernacular, "those that go down") may be expected at stage 3; this problem becomes serious at stage 4 and extremely troublesome at stage 5. In the higher stages of drought, small fires of an acre or less may require the attendance of a pumper crew for a week or longer before they are completely extinguished.

A further word of explanation is needed to make clear the significance of the drought index in the spruce-fir region. The direct association of deep burning fires and costly suppression with high drought conditions is well understood. But these fires will not necessarily be major fires. Often the summer season is characterized by subnormal, but well-distributed, rainfall. In such seasons the drought index climbs persistently upward because there is little net rain. However, the buildup and spread indexes of the National System may remain low. Under these conditions, the upper litter layer, represented by the buildup index, will be relatively moist, and with little wind, the fires that start move slowly, but burn deeply, creating a potentially dangerous situation. Given a week or two of warm, dry weather, the buildup index will rise. Then may come a windy day, when all indexes are high, and the stage is set for such devastating high-intensity fires as occurred in Maine in the fall of 1947 and the summer of 1952.

4. Drought conditions in the fall or winter result from prior development during the preceding summer. In the Southern Appalachians, drought stages of 3 or 4 are to be expected in the fall of most years. Fall fires are persistent in that region, but the usual careful preparation of firelines is sufficient to contain the burning perimeter, once the forward spread is stopped. In years when the fall drought reaches the fifth and sixth stages, however, normal fireline preparation is not enough. Instances of fires escaping under firelines through dead roots or buried tree limbs a foot or more beneath the mineral soil surface were reported in the Southern Appalachians during the fall seasons of 1952 and 1953.

5. The significance of the drought index changes from the deep duff country to areas of lighter fuels. In deep fuel areas it is important to know when drought starts to build up; thus, fire control managers in these areas are interested in all stages of drought. In light fuel areas, such as those where the litter and duff average considerably under 10 tons per acre, the lower stages of drought are less important. In such areas the drought index described here may not be an important factor in fire suppression until it reaches the upper half of the scale. There are several possible exceptions to this generalization about the nonimportance of the lower half of the scale in light fuel areas. For instance, in areas where a certain stage of drought is associated with the incidence of crown fires or with the development of grassland curing. Although these possible associations are worth considering, they were not studied in the preparation of this report.

APPENDIX

THE THEORY OF SOIL MOISTURE DEPLETION IN WILDLAND AREAS

The following analysis presents the physical theory and general framework for a drought index which should function throughout a wide range of climatic and rainfall conditions in forested or wildland areas. At the present time there are gaps in our knowledge of the precise form of the relationships between certain variables. These gaps may take several years to fill. Meanwhile, if the essential physical concepts and theory can be developed, the gaps can be replaced by effective assumed relationships. Such assumptions will permit the use of an index, or method for estimating drought, during the time in which more data are being obtained and with little subsequent change required in the general system.

In developing the equations which describe the degree of drought or moisture deficiency which exists in a forested or wildland area, it will be assumed that:

1. From the standpoint of fire control, the significant moisture relationships are those which exist in an upper layer of soil and a covering layer of duff. The field capacity of the soil-duff layer will be taken as 8.0 inches of water in excess of the moisture which the layer holds at the wilting point. For a heavy soil at field capacity, 8.0 inches of free water would require a soil layer about 30 to 35 inches deep. In a lighter sandy soil the depth would be somewhat greater.

2. The soil-duff layer gains moisture from rainfall and loses moisture by evapotranspiration. Its lowest level of moisture content occurs at the wilting point.

3. The evapotranspiration rate will be a function of the weather variables and the vegetation density.

4. The vegetation density, and hence the rate at which the vegetation can remove moisture from the soil-duff layer when the weather variables are constant, is a function of the amount of mean annual rainfall. This rate will be characterized by a single parameter defined as the evapotranspiration timelag.[3]

5. As a first approximation, simple exponential functions can be used to express the relationships between essential variables in the basic equations.

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[3] The tendency of vegetation to adjust to the rainfall of a given area is discussed by Tannehill (1947, pp. 39, 67).

If the weather variables which affect transpiration such as temperature, relative humidity, and sunshine are constant, and if the rate at which the soil-duff layer loses water is directly proportional to the amount of water in the layer, then an equation can be written in the form

$$w = w_c \exp(-\tau/t) \tag{1}$$

in which

w = the inches of water available for plant use in the soil-duff layer,

w_c = the corresponding field capacity in inches of available water in the layer,

τ = the time in days during which the soil-duff has been losing moisture, and

t = the evapotranspiration timelag in days (the time required for the moisture content of the soil-duff layer to drop to $1/e$ of its initial value, where e is the base of natural logarithms).

Equation (1) is the basic equation in the analysis and is identical to that given by Liacos (1962) for soil moisture depletion in a layer 90 cm. deep in grassland plots. He discusses briefly the work of several other investigators who also found exponential depletion curves for different types of vegetation cover. Their results are also in agreement with the statements of Thornthwaite (1948) on soil moisture depletion. However, agreement on this point is not unanimous; Veihmeyer and Hendrickson (1955) suggest a linear type of depletion curve.

The next step in the development of the equations is to establish a relationship between the evapotranspiration timelag t, the temperature T (maximum daily temperature will be used), and the mean annual rainfall R. This part of the analysis will depart considerably from the procedures of other investigators. It will be assumed that a functional equation can be written in the form

$$1/t = f(R, T) \tag{2}$$

where t is the evapotranspiration timelag for maximum daily temperature T in a vegetated area for which the mean annual rainfall is R inches per year. Vegetation density does not appear in this equation because, in accordance with assumption 4 above, this variable is a function of R. It is simpler to write the left member of Equation (2) as $1/t$ instead of t because at a given moisture content the evapotranspiration rate varies directly as $1/t$. Other factors such as latitude, slope and aspect, and probably soil type, affect vegetation density; but it will be assumed that their effects are small compared to that of rainfall. Perhaps more questionable is the apparent omission of sunshine intensity, wind, and relative humidity from Equation (2). However, as a first approximation, it will be assumed that over a period of time Equation (2) will reflect the mean contribution of these variables.

The next step is to write Equation (2) in a more restricted form,

$$1/t = f_1(T)f_2(R) \tag{3}$$

in which f_1 and f_2 are functions which for the time being can remain undetermined. Equation (3) is illustrated by the curves in figure 7 in which t is shown as a function of R for two different values of T. Since there would be no vegetation for $R = 0$, it might appear that $t \to \infty$ as $R \to 0$. However, there would still be evaporation which would require finite values of t as $R \to 0$. Also, that region of the t curve in which $R \to 0$ can be regarded as a mathematical extrapolation from the region in which a definite relation exists between t and R. An analogous situation exists in the region where $R \to \infty$. This region is best interpreted as that for which the root systems of the vegetation have access to free water. Probably 150 inches of well-distributed annual rainfall could be considered "infinite" for the middle latitude regions. Thus, for any given value of T, the timelag t should approach a limiting value as R becomes very large.

The equation for estimating the daily decrease in the available moisture (that is, the daily increment in moisture deficiency) can be found from Equations (1) and (3). Taking the logarithm of both sides of Equation (1), differentiating with respect to τ, and combining with Equation (3), gives

$$\frac{1}{w}\frac{dw}{d\tau} = \frac{-1}{t} = -f_1(T)f_2(R) \tag{4}$$

Taking the logarithm of both sides of this equation gives a form suitable for solution by slide-rule methods. This form is

$$\log(-dw) = \log w + \log f_1(T) + \log f_2(R) + \log d\tau \tag{5}$$

The moisture deficiency Q will be defined by the equation

$$Q = w_c - w$$

from which

$$dw = -dQ$$

Equation (5) can thus be written in the form

$$\log dQ = \log(w_c - Q) + \log f_1(T) + \log f_2(R) + \log d\tau \tag{6}$$

Equations (4), (5), and (6) are alternate general forms of the desired drought equation. None of these equations, however, can be used for numerical computations of dQ (or -dw) until $f_1(T)$ and $f_2(R)$ have been determined and the associated constants evaluated. Considerable information is available for estimating the form of $f_1(T)$, but little is known about the precise form of $f_2(R)$. However, for the purpose of first approximation, a preliminary equation will be derived for $f_2(R)$. When more information is available, new calculations based on a more precise form of this function can be readily obtained with no change in the procedure or form of the results.

In determining the functions $f_1(T)$ and $f_2(R)$, it is desirable to write the evapotranspiration timelag t with the more specific notation $t_{T,R}$. For example, $t_{80,50}$ represents the timelag t for a daily maximum temperature of 80° F. in a region where the mean annual rainfall is 50 inches. Differentiating Equation (1) with respect to τ, gives for the evapotranspiration rate $dw/d\tau$:

$$\frac{dw}{d\tau} = \left(-w_c/t\right) \exp(-\tau/t)$$

Letting $\tau = 0$ and changing to the specific notation results in

$$\left(\frac{dw_{T,R}}{d\tau}\right)_{\tau = 0} = -w_c/t_{T,R} \tag{7}$$

The left member of this equation is the evapotranspiration rate at $\tau = 0$ and is equivalent to a quantity usually defined as the potential evapotranspiration rate. This quantity represents the rate for a saturated soil and is shown as a function of T in figure 8. The curve in this figure was plotted from tabulated values given by Nelson (1959)[4] which in turn were based on the work of Thornthwaite (1948) and the data of Moyle and Zahner (1954). The vegetation density (and hence the value of R) corresponding to the curve in figure 8 is not precisely known, but it will be assumed that R is 50 inches per year.

If two equations are formed from Equation (7), one with $T = T$ and the other with $T = T_o$ and with R having the same value in both equations, then their ratio can be expressed as

$$\frac{t_{T,R}}{t_{T_o,R}} = \left[\frac{dw_{T,R}}{d\tau} \bigg/ \frac{dw_{T_o,R}}{d\tau}\right]^{-1}_{\tau = 0} \tag{8}$$

where T_o is some reference temperature. Forming similar ratios from Equation (3) and holding R constant in any given ratio, yields

$$\frac{t_{T,\infty}}{t_{T_o,\infty}} = \frac{t_{T,0}}{t_{T_o,0}} = \frac{t_{T,R}}{t_{T_o,R}} = \left[\frac{f_1(T)}{f_1(T_o)}\right]^{-1} \tag{9}$$

---

[4] An extensive list of 28 references on drought, soil moisture, and vegetation-soil moisture relationships is cited in Nelson's paper.

because $f_2(R)$ cancels out. Thus, a comparison of Equation (8) with the last of Equations (9) shows that the function of $f_1(T)$ is directly proportional to the potential evapotranspiration rate for a given value of R (that is, for a given vegetation density).

The form of the relationship represented by Equation (3) and illustrated by the curves in figure 7 may not be precisely known for several years. Meanwhile, it is necessary to approximate the relationship with an empirical equation which seems reasonable and is consistent with the basic physical concepts involved. For this purpose, it will be assumed that Equation (3) can be approximated by the exponential equation

$$t_{T,R} - t_{T,\infty} = K \exp(-aR)$$

in which a is a constant and K is a function of T only. However, when $R = 0$, then $t_{T,R} = t_{T,0}$, and therefore $K = t_{T,0} - t_{T,\infty}$. Thus, it follows that

$$y = y_o \exp(-aR) \qquad (10)$$

where

$$y+1 = \left(t_{T,R}\right) / \left(t_{T,\infty}\right)$$

and

$$y_o+1 = \left(t_{T,0}\right) / \left(t_{T,\infty}\right)$$

The curve in figure 9 shows y+1, or the ratio $\left(t_{T,R}\right) / \left(t_{T,\infty}\right)$, plotted as a function of R. Substituting the value of $t_{T,\infty}$ from Equation (9) into Equation (10) gives

$$t_{T,R} = \left[t_{T_o,\infty}\, f_1(T_o) / f_1(T)\right] \left[1+y_o \exp(-aR)\right]$$

where t is written with the appropriate subscripts for the specific notation form. A comparison of this equation with Equation (3) shows that $f_2(R)$ can be regarded as the quantity

$$f_2(R) = \left(t_{T_o,\infty}\, f_1(T_o) \left[1+y_o \exp(-aR)\right]\right)^{-1} \qquad (11)$$

Equation (4) can now be written in the form

$$\frac{1}{w_c-Q}\,\frac{dQ}{d\tau} = \frac{f_1(T)}{t_{T_o,\infty}\, f_1(T_o) \left[1+y_o \exp(-aR)\right]} \qquad (12)$$

in which w_c-Q has replaced w.

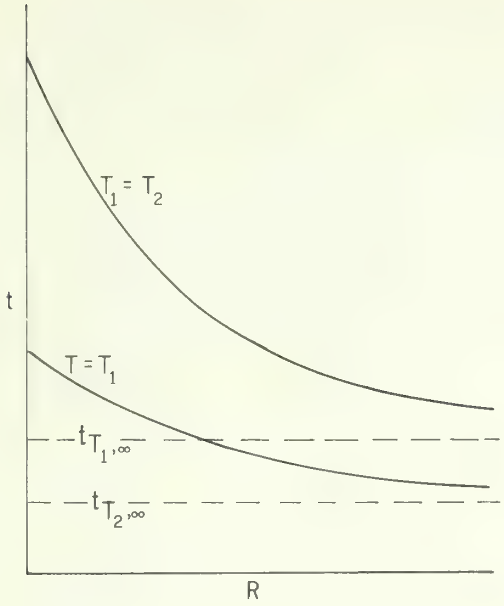

Figure 7.--The possible relationship between the evapotranspiration timelag t, the daily maximum temperature T, and the mean annual rainfall R. The line $t = t_{T_1,\infty}$ represents the timelag for $T = T_1$ and $R = \infty$ and is an asymptote for the curve for which $T = T_1$. Likewise, the line $t = t_{T_2,\infty}$ is an asymptote for the curve for which $T = T_2$.

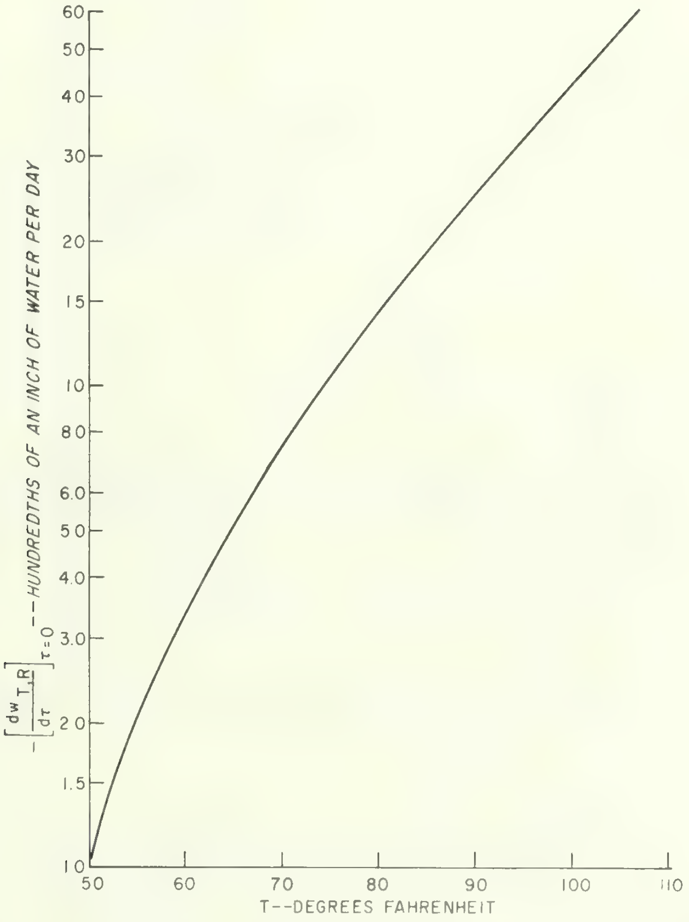

Figure 8.--Daily potential evapotranspiration as a function of maximum daily temperature.

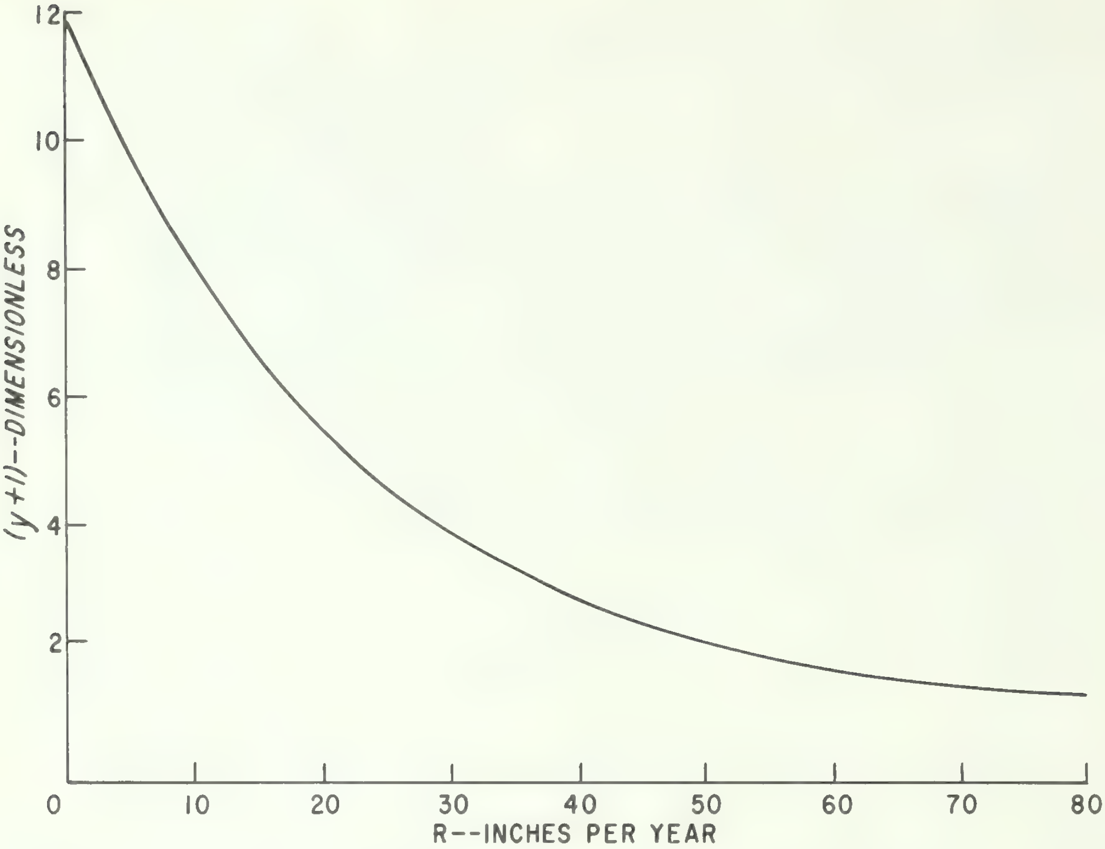

Figure 9.--The relationship between the dimensionless quantity (y+1) and the mean annual rainfall R.

In the range from T = 50° F. to T = 110° F., the potential evapotranspiration rate curve in figure 8 can be closely approximated by the empirical equation

$$-\left[\frac{dw_{T,\,50}}{d\tau}\right]_{\tau\,=\,0} = .352\ \exp(.0486T) - 3.015 \qquad (13)$$

the units of which are in hundredths of an inch of water per day. From Equations (8) and (9) it follows that

$$\frac{f_1(T)}{f_1(T_o)} = \left[\frac{dw_{T,\,R}}{d\tau}\Big/\frac{dw_{T_o,\,R}}{d\tau}\right]_{\tau\,=\,0} \qquad (14)$$

The potential evapotranspiration ratio in the right member of this equation will be the same for all values of R; hence it can be expressed in terms of the curve in figure 8 or Equation (13). If the reference temperature T_o is set at 80° F., then Equation (13) gives a numerical value of -14.18 hundredths of an inch per day for the potential evapotranspiration rate. This is also the value of the denominator of the ratio in the right member of Equation (14) when R = 50 inches per year. Hence, combining Equations (13) and (14) gives

$$f_1(T)\big/ f_1(T_o) = .02481 \exp(.0486T) - 2.113 \tag{15}$$

The values of the constants $\underline{a}$ and y_o in Equation (10) will eventually have to be determined by experiment, but tentative values can be found by assuming values of y for two different values of R in Equation (10). For example, if y = 7 when R = 10 inches per year and if y = 1.2 when R = 50 inches per year, then $\underline{a}$ = .04409 years per inch and the dimensionless constant y_o is 10.88.

The last constant which must be evaluated in Equation (12) is $t_{T_o,\infty}$. The first step in this procedure is to form two equations from Equation (3), one with R = R and the second with R = R_o. If T is the same in both equations, then it follows from Equation (11) that the ratio of the two equations is

$$\frac{t_{T,R}}{t_{T,R_o}} = \frac{f_2(R_o)}{f_2(R)} = \frac{1 + 10.88 \exp(-.04409R)}{1 + 10.88 \exp(-.04409R_o)} \tag{16}$$

If R = ∞ and R_o = 50 inches per year, then Equation (16) gives

$$t_{T,\infty} = .4545\, t_{T,50} \tag{17}$$

On combining Equations (13) and (7) and solving for $t_{T,50}$ one obtains when R = 50 inches per year

$$t_{T,50} = \frac{w_c}{.352 \exp(.0486T) - 3.015}$$

When $T = T_o = 80°$ F. (arbitrarily chosen as the reference temperature) and w_c = 800 hundredths of an inch of water, then, from the above equation, $t_{80,50}$ = 56.41 days. Hence, from Equation (17), it follows that $t_{80,\infty}$ = 25.64 days. Expressing Equation (12) in terms of the evaluated numerical constants with only dQ in the left member gives

$$dQ = \frac{[800-Q]\,[.968 \exp(.0486T) - .830]\, d\tau}{1 + 10.88 \exp(-.0441R)} \times 10^{-3} \tag{18}$$

the form of the equation needed for computing the drought factor dQ. This computing is most conveniently done on a daily basis in which case the time increment $d\tau$ is placed equal to 1 day. Special slide rules based on the logarithmic form of Equation (18) can be used to obtain rapid solutions of this equation, although the tables given in the main body of the report are probably best for routine use.

In the derivation of the basic equations, the fuel layer has been included with the soil. In the setting of w_c at 8.0 inches of water, it is assumed that w_c refers both to the soil and to the fuel layer. Some slight improvement might be obtained by treating the layers separately, but the procedure would be more complex. It is doubtful that any substantial improvement in drought evaluation can be obtained unless the soil and fuel zones are divided into a number of discrete layers and computer methods are used. Although such methods would permit the use of a larger value of w_c (possibly 15 or more inches of water), it is not likely that the improvement would justify the complexity of such a system at the present time.

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U.S.D.A. Forest Service Research Paper SE-39

September 1968

SOUTHERN PINE LOG GRADES FOR YARD AND STRUCTURAL LUMBER

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Southeastern Forest Experiment Station
U.S. Department of Agriculture-Forest Service
Asheville, North Carolina

This is one of a group of four publications by the Southeastern Forest Experiment Station pertaining to southern pine log and tree grade lumber recovery studies. The four publications are:

Southern Pine Log Grades for Yard and Structural Lumber, U.S.D.A. Forest Service Research Paper SE-39, by J. G. Schroeder, R. A. Campbell, and R. C. Rodenbach.

Southern Pine Tree Grades for Yard and Structural Lumber, U.S.D.A. Forest Service Research Paper SE-40, by J. G. Schroeder, R. A. Campbell, and R. C. Rodenbach.

Combined Effects of Drying, Surfacing, and Trimming on Grade and Volume of Southern Pine Lumber, U.S.D.A. Forest Service Research Note SE-93, by B. E. Carpenter, Jr., and J. G. Schroeder.

Southern Yellow Pine Tree Overruns and Lumber Distributions, U.S.D.A. Forest Service Research Paper SE-41, by D. O. Yandle.

SOUTHERN PINE LOG GRADES FOR YARD AND STRUCTURAL LUMBER

ERRATA

Southern Pine Tree Grades for Yard and Structural Lumber

Table 5, page 10, under Grade B, 3-Log Trees, 18-inch diameter trees, column D& 1C, change 16 to 15.

Table 6, page 11, under Grade C, 2-Log Trees, 14-inch diameter trees, column 1D, change 16 to 17; under Grade C, 4-Log Trees, 12-inch diameter, column 1D, change 14 to 24.

Lumber yields by grade were analyzed separately for each species, but because of similarities in yields, the species were combined into two groups. As in tree grading, these groups are: (1) loblolly, shortleaf, and pond pine; and (2) longleaf and slash pine.

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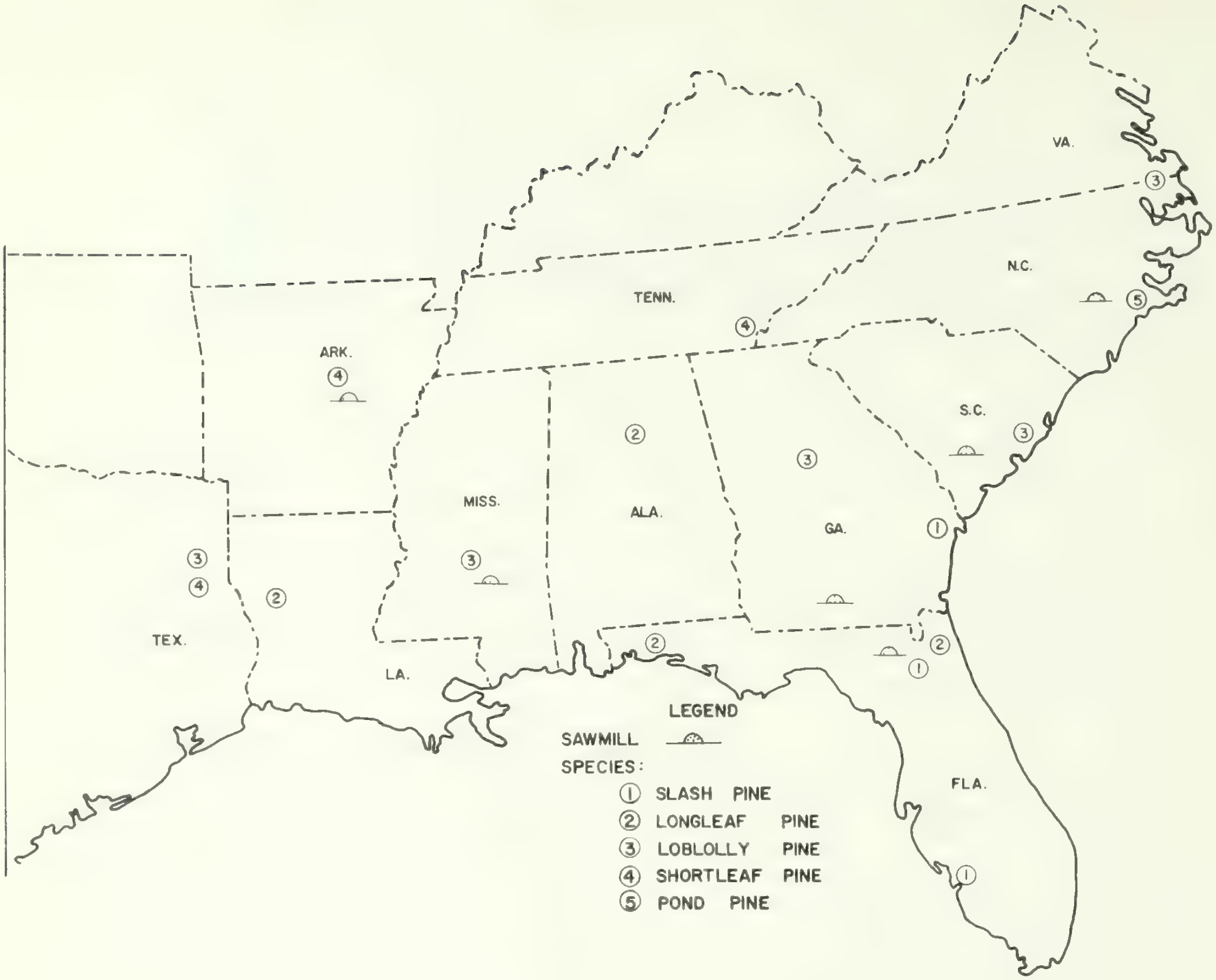

Figure 1.--Location of study sawmills and areas from which sample trees were selected.

Both the older knot-count grading system and the new clear-face grading system stratified log values, as determined from predicted lumber grade-yields, into distinct classes. However, neither system was superior to the other in reducing unexplained variance in value (yields). Clear-face log grades are recommended because they are easier and quicker to use than the knot-count grades, and predictions of log values based on lumber grade-yields are just as accurate.

Regression equations for lumber-yield percentages by lumber grade, as a function of log diameter, were computed for each species group and clear-face log grade. The equations, mean lumber yield, standard errors, and correlation coefficients are given in appendix tables 3 and 4.

GRADING PROCEDURE

General

These log grades apply to cut merchantable loblolly, shortleaf, pond, longleaf, and slash pine saw logs. Merchantable logs are those logs at least 6 inches in diameter inside bark, having a net log scale of at least one-third their gross log scale. Logs from 8 to 20 feet long can be graded by these rules. This system is also used for grading trees that contain only one 16-foot saw log.

Logs are graded on the external appearance of the faces.[1] The number of clear faces,[2] together with evaluation of the amount of sweep and/or rot in the log, determines the log grade.

Grading Rules

Logs are graded in three steps. First, determine the number of clear faces on the log. Include as many defects as possible in one face so the maximum number of clear faces are obtained. If the log has three or more clear faces, classify it a tentative Grade 1; if it has one or two clear faces, a tentative Grade 2; and if it has no clear face, a tentative Grade 3.

The second step is to examine the log for sweep. If sweep in the log amounts to 3 inches or more and equals or exceeds one-third the scaling diameter, lower the grade of the log one grade if it was a tentative Grade 1 or 2 after the clear-face examination. All logs are classified "cull," regardless of the number of clear faces, if the total scalable defect deduction exceeds two-thirds the gross scale of the log.

The third step in log grading is to examine the log for evidence of rot. If conks, massed hyphae, punk knots, or other evidence of rot are found on the log, reduce the grade of the log one grade as was done for sweep. Again, remember that all logs are classified cull if the total scalable defect deduction (rot and/or sweep) exceeds two-thirds the gross scale of the log.

The grading procedure in abbreviated form is outlined below:

SOUTHERN PINE LOG GRADES

Grade 1 - logs with 3 or 4 clear faces.

Grade 2 - logs with 1 or 2 clear faces.

Grade 3 - logs with no clear faces.

---

[1] A face is one-fourth the circumference of the log surface and extends the full length of the log.

[2] Clear faces are those free from knots measuring more than ½ inch in diameter, overgrown knots of any size, and holes more than ¼ inch in diameter. Faces may be rotated, if necessary, to obtain the maximum number of clear faces on the log.

After the tentative log grade is established from the face examination, the log will be reduced one grade for each of the following:

> (1) Sweep. Degrade any tentative Grade 1 or 2 log one grade if sweep is 3 inches or more and equals or exceeds one-third the scaling diameter of the log.
>
> (2) Heart rot. Degrade any tentative Grade 1 or 2 log one grade if conks, massed hyphae, punk knots, or other evidence of advanced heart rot are found.
>
> NOTE: No log will be degraded below Grade 3 if its net scale is at least one-third the gross log scale after deductions have been made for sweep and/or rot. Logs with total scaling deductions for sweep and rot exceeding two-thirds the gross scale of the log will be classified cull.

The lumber grade-yields for the two species groups are presented in tables 1 and 2 by log-scaling diameter. (In these tables, Grade 1D includes No. 1 dimension and No. 1 dense; Grade 2D includes No. 2 dimension, No. 2 dense, and "Special"; Grade 3D includes No. 3 dimension and No. 3 dense.)

DISCUSSION

The log grades presented here are the result of many years of Forest Service research, and represent much valuable cooperation from industry and private foresters.

The regression equations and the predicted yields in this report are based on rough-green lumber yields. U. S. D. A. Forest Service Research Note SE-93, "Combined Effects of Drying, Surfacing, and Trimming on Grade and Volume of Southern Pine Lumber," can be used with this paper to adjust the yields to a dry, surfaced base, if this is desired (Carpenter and Schroeder 1968). The overruns and underruns that might be expected from logs of various diameters by the Doyle, Scribner Decimal C, and International log rules have been published in a companion publication, U. S. Forest Service Research Note SE-56, by Rodenbach (1966).

The lumber grade-yields in this paper are South-wide averages; it is not likely they will predict precisely any particular mill's output. Because mills saw to different product mixes, depending on market conditions, it would be best if a user of this grading system developed his own performance data by conducting a mill-scale study. This can be done easily by selecting approximately 50 logs in each grade and making a tally, by grade, width, and thickness, of the lumber produced from each grade and diameter class of logs.

The log grades presented here have been approved as standard by the Chief of the Forest Service, and replace the previously used knot-count grades. They are simple and easy to apply, and will stratify logs into distinct value classes if the logs are carefully and accurately graded.

Table 1. --Lumber grade-yield for longleaf-slash pine

GRADE 1 LOGS (Rough-green, basis: 113 logs)

D. i. b.	B&B	C	D& 1C	2C	3C	4C	1D	2D	3D	4D
Inches	Percent									
6	0	0	0	0	0	0	0	0	0	0
8	3	19	21	3	0	1	52	1	0	0
10	11	16	23	6	1	1	38	2	1	1
12	16	16	25	8	1	1	29	2	1	1
14	18	18	26	8	1	1	24	2	1	1
16	18	22	28	8	2	0	21	1	0	0
18	18	25	29	7	2	0	19	0	0	0
20	16	29	30	6	2	0	17	0	0	0

GRADE 2 LOGS (Rough-green, basis: 136 logs)

6	3	6	24	21	0	0	35	11	0	0
8	4	11	24	16	1	0	35	8	1	0
10	5	14	26	14	1	0	32	7	1	0
12	7	16	27	14	1	0	27	7	1	0
14	10	17	29	14	1	0	22	7	0	0
16	13	17	30	16	0	0	17	7	0	0
18	15	17	32	18	0	0	11	7	0	0
20	18	17	33	20	0	0	5	7	0	0

GRADE 3 LOGS (Rough-green, basis: 645 logs)

6	0	1	21	37	1	0	18	20	2	0
8	1	2	14	44	2	0	18	18	1	0
10	2	3	12	47	3	0	17	15	1	0
12	2	5	13	48	3	0	15	12	2	0
14	3	7	16	47	4	0	12	9	2	0
16	3	8	21	46	4	0	9	6	3	0
18	3	11	26	44	4	0	6	2	4	0
20	4	13	31	41	4	0	3	0	4	0

Table 2.--Lumber grade-yield for loblolly-shortleaf-pond pine

GRADE 1 LOGS (Rough-green, basis: 267 logs)

D.i.b.	B&B	C	D& 1C	2C	3C	4C	1D	2D	3D	4D
Inches	Percent									
6	0	0	15	22	6	0	51	4	2	0
8	6	7	20	15	2	0	45	4	1	0
10	13	12	22	10	1	0	37	4	1	0
12	18	14	23	9	1	0	30	4	1	0
14	21	14	23	9	2	1	25	4	1	0
16	23	14	22	10	4	1	20	4	2	0
18	25	13	21	12	6	1	15	4	3	0
20	26	12	20	15	8	1	11	4	3	0
GRADE 2 LOGS (Rough-green, basis: 320 logs)										
6	0	0	7	15	2	1	46	23	6	0
8	2	3	15	18	1	1	40	16	4	0
10	6	6	19	19	1	0	34	12	3	0
12	8	7	20	20	3	0	29	10	3	0
14	10	8	20	19	4	1	25	10	3	0
16	12	9	19	19	5	1	20	11	4	0
18	13	9	18	19	7	1	17	12	4	0
20	14	9	16	19	8	2	13	14	5	0
GRADE 3 LOGS (Rough-green, basis: 1,091 logs)										
6	0	0	8	26	3	1	21	30	10	1
8	0	1	8	34	4	0	15	28	10	0
10	1	1	8	35	5	0	12	27	11	0
12	2	2	8	34	6	1	10	26	11	0
14	2	3	8	30	8	1	10	25	12	1
16	3	4	7	26	10	2	10	24	13	1
18	4	4	7	21	12	3	11	23	13	2
20	5	5	7	15	15	3	12	22	14	2

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Appendix

Table 3.--Regression equations, mean lumber yields, standard errors, and correlation coefficients for longleaf-slash pine

Lumber grade	Regression equation			Mean lumber yield	Standard error of the mean	Correlation coefficient
	Constant	x D.i.b.	x 1/D.i.b.	Percent	Percent	
GRADE 1 LOGS (Basis: 113 logs)						
B&B	+0.76013	-0.01779	-4.67430	14.722	1.246	.320
C	-0.51709	+0.03124	+3.70063	18.439	1.297	.200
D&1C	+0.16490	+0.00771	-0.10034	25.378	1.341	.159
2C	+0.39349	-0.01080	-2.25193	7.004	1.034	.142
3C	+0.03964	+0.00007	-0.35144	1.129	0.405	.156
4C	+0.05797	-0.00237	-0.25778	0.661	0.336	.065
1D, 1 Dense	-0.41341	+0.01307	+6.59817	30.000	1.594	.526
2D, 2 Dense, Spcl.	+0.24990	-0.01022	-1.26270	1.605	0.540	.137
3D, 3 Dense	+0.13673	-0.00569	-0.70778	0.621	0.370	.110
4D	+0.12775	-0.00521	-0.69261	0.442	0.443	.080
GRADE 2 LOGS (Basis: 136 logs)						
B&B	-0.19548	+0.01702	+0.77997	7.150	0.838	.298
C	+0.34407	-0.00462	-1.53154	14.863	1.028	.210
D&1C	+0.16403	+0.00819	+0.13548	27.017	1.513	.110
2C	-0.21855	+0.01577	+1.99374	14.722	1.753	.067
3C	+0.08268	-0.00339	-0.38686	0.793	0.246	.091
4C	-0.00673	+0.00046	+0.02373	0.075	0.039	.160
1D, 1 Dense	+0.82275	-0.03491	-1.57483	27.740	1.921	.269
2D, 2 Dense, Spcl.	-0.04044	+0.00368	+0.75248	7.163	1.445	.053
3D, 3 Dense	+0.05302	-0.00240	-0.22510	0.466	0.299	.058
4D	No equation					
GRADE 3 LOGS (Basis: 645 logs)						
B&B	+0.01884	+0.00135	-0.17895	1.186	0.161	.204
C	-0.11904	+0.01131	+0.36896	3.047	0.281	.261
D&1C	-0.62462	+0.03775	+3.64410	14.313	0.744	.161
2C	+0.94337	-0.01975	-2.73983	44.888	1.089	.121
3C	+0.06472	-0.00019	-0.35040	2.388	0.302	.123
4C	+0.02239	-0.00083	-0.10803	0.244	0.059	.083
1D, 1 Dense	+0.42675	-0.01768	-0.81738	16.626	0.917	.010
2D, 2 Dense, Spcl.	+0.35806	-0.01780	-0.28279	15.593	0.825	.177
3D, 3 Dense	-0.08187	+0.00524	+0.43426	1.669	0.316	.048
4D	-0.00857	+0.00059	+0.03003	0.045	0.033	.086

Table 4.--Regression equations, mean lumber yields, standard errors, and correlation coefficients for loblolly-shortleaf-pond pine

GRADE 1 LOGS (Basis: 267 logs)

Lumber grade	Regression equation			Mean lumber yield	Standard error of the mean	Correlation coefficient
	Constant	x D.i.b.	x 1/D.i.b.			
				Percent	Percent	
B&B	+0.48051	-0.00349	-3.11761	20.329	0.943	.304
C	+0.59195	-0.01601	-3.11068	13.248	0.783	.151
D&1C	+0.47874	-0.00994	-1.58403	21.863	0.933	.077
2C	-0.46580	+0.02201	+3.49207	10.893	0.851	.186
3C	-0.30721	+0.01505	+1.63903	3.153	0.419	.364
4C	+0.02878	-0.00052	-0.20580	0.621	0.157	.087
1D, 1 Dense	+0.28827	-0.01431	+2.22393	24.077	1.274	.427
2D, 2 Dense, Spcl.	+0.02384	+0.00087	+0.04275	3.966	0.543	.025
3D, 3 Dense	-0.08749	+0.00488	+0.45704	1.686	0.343	.162
4D	-0.03158	+0.00146	+0.16326	0.165	0.080	.182
GRADE 2 LOGS (Basis: 320 logs)						
B&B	+0.10914	+0.00401	-0.93187	8.753	0.680	.300
C	+0.23960	-0.00358	-1.47516	7.245	0.549	.239
D&1C	+0.62387	-0.01632	-2.71914	18.558	0.857	.141
2C	+0.31408	-0.00455	-0.78478	18.978	1.045	.034
3C	-0.14709	+0.00995	+0.63107	3.709	0.442	.285
4C	-0.05209	+0.00266	+0.29661	0.744	0.188	.113
1D, 1 Dense	+0.37039	-0.01515	+1.20523	26.490	1.306	.356
2D, 2 Dense, Spcl.	-0.35451	+0.01689	+3.00798	11.477	1.035	.134
3D, 3 Dense	-0.10603	+0.00599	+0.76717	3.621	0.539	.078
4D	+0.00265	+0.00010	+0.00286	0.424	0.177	.010
GRADE 3 LOGS (Basis: 1,091 logs)						
B&B	-0.05042	+0.00477	+0.12210	1.458	0.123	.306
C	-0.03384	+0.00399	+0.06337	1.671	0.140	.248
D&1C	+0.12283	-0.00244	-0.17443	7.858	0.426	.026
2C	+1.10626	-0.03851	-3.70502	31.447	0.790	.169
3C	-0.13008	+0.01236	+0.54121	6.041	0.320	.249
4C	-0.08072	+0.00477	+0.37092	0.866	0.145	.137
1D, 1 Dense	-0.19297	+0.01063	+2.02428	12.406	0.688	.128
2D, 2 Dense, Spcl.	+0.29409	-0.00398	+0.15185	26.484	0.840	.063
3D, 3 Dense	+0.04160	+0.00436	+0.21872	11.153	0.632	.041
4D	-0.07674	+0.00404	+0.38697	0.617	0.154	.091

U.S.D.A. Forest Service Research Paper SE-40

September 1968

SOUTHERN PINE TREE GRADES FOR YARD AND STRUCTURAL LUMBER

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Asheville, North Carolina

This is one of a group of four publications by the Southeastern Forest Experiment Station pertaining to southern pine log and tree grade lumber recovery studies. The four publications are:

Southern Pine Log Grades for Yard and Structural Lumber, U.S.D.A. Forest Service Research Paper SE-39, by J. G. Schroeder, R. A. Campbell, and R. C. Rodenbach.

Southern Pine Tree Grades for Yard and Structural Lumber, U.S.D.A. Forest Service Research Paper SE-40, by J. G. Schroeder, R. A. Campbell, and R. C. Rodenbach.

Combined Effects of Drying, Surfacing, and Trimming on Grade and Volume of Southern Pine Lumber, U.S.D.A. Forest Service Research Note SE-93, by B. E. Carpenter, Jr., and J. G. Schroeder.

Southern Yellow Pine Tree Overruns and Lumber Distributions, U.S.D.A. Forest Service Research Paper SE-41, by D. O. Yandle.

SOUTHERN PINE TREE GRADES FOR YARD AND STRUCTURAL LUMBER

by

J.G. Schroeder, R.A. Campbell, and R.C. Rodenbach

Since the 1930's, Forest Service and industry researchers have worked toward development of an objective grading system for southern pine. Various systems for grading pine saw logs resulted from these studies, but tree grades were not developed. For the most part, trees were evaluated on personal judgment or by applying some grading system in a log-by-log manner to each log in the tree.

Log-by-log grading in the past has met with disfavor for two primary reasons. First, it is time consuming; and secondly, the accuracy is questionable, especially in tall timber. The log grades used required the grader to estimate log dividing lines on the tree stem, and also to count knots on the section being graded, to estimate size of the knots, and to estimate the diameter inside bark at the top of each log. It is likely that accurate grading decreased with tree height.

In 1961, the Southeastern Forest Experiment Station initiated a study to develop tree grades for southern pine based on lumber outturn. The field portion of the study was completed in late 1964. The results, a practical tree grading system, are presented in this report.

THE STUDY

When the tree grade study was begun, a considerable body of information was available to the project. This information, tree diagrams and lumber yields by grade from the trees, was on record from sawing studies conducted in 1956 and 1959. These data formed the basis from which trial tree grades were developed.

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The sawing studies had been conducted at several mills throughout the South and included loblolly (Pinus taeda L.), shortleaf (Pinus echinata Mill.), longleaf (Pinus palustris Mill.), and slash (Pinus elliottii Engelm.) pines. Figure 1 shows the location of the study sawmills and the areas from which trees were selected.

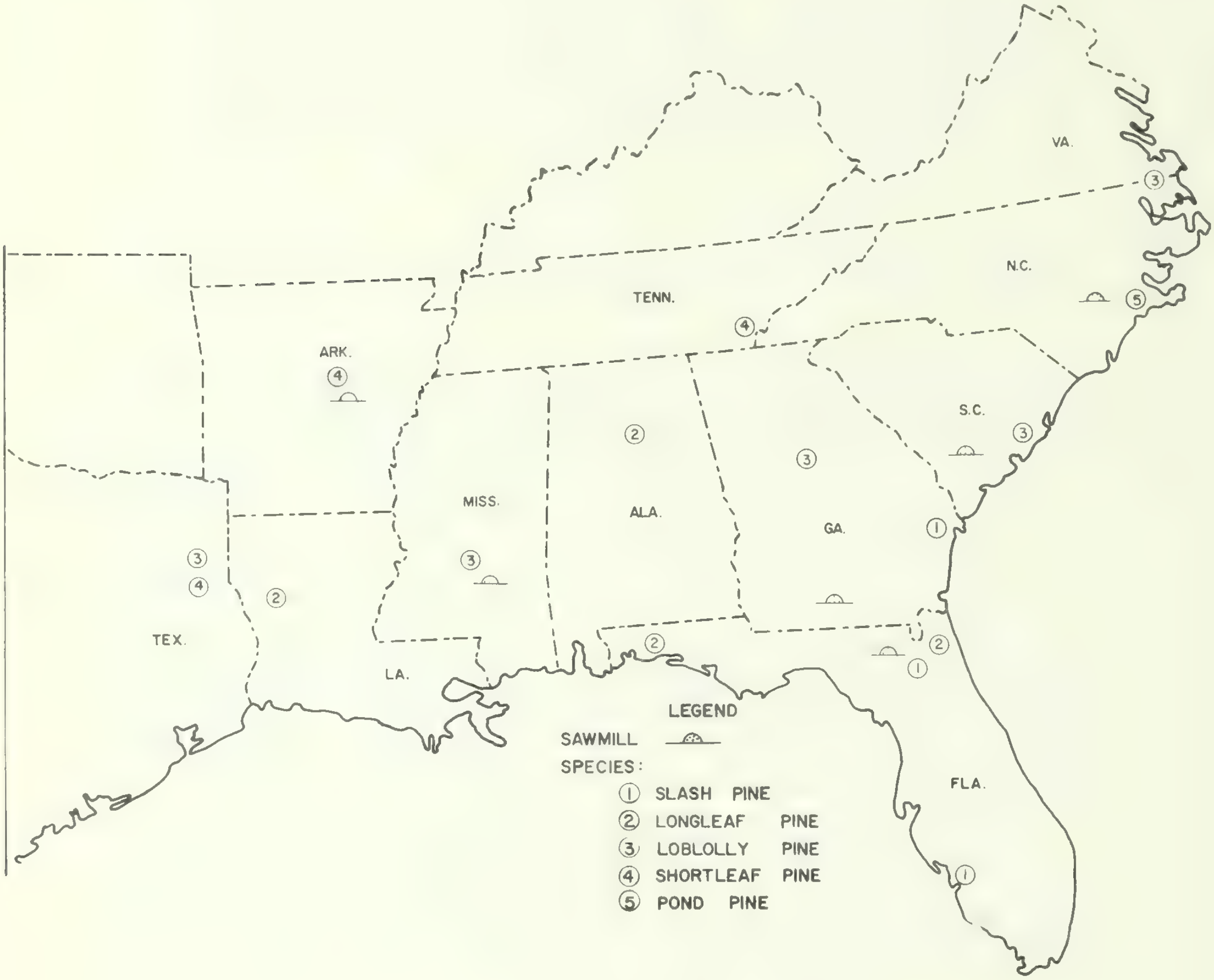

Figure 1.--Location of study sawmills and areas from which sample trees were selected.

Several tree grading systems were developed from analyses of the lumber grade-yield data and the tree diagrams. But, in the final analysis, two grading systems were superior from the standpoint of reducing unexplained variance. These were: (1) a clear-face grading system, and (2) a knot-count grading system. Both of these were retained until an additional test could be made.

In 1964, an additional lumber grade-yield study was conducted. In this study, trees of the four previously mentioned species were selected from stands ranging from Texas to Virginia, and a sample of pond pine (Pinus serotina Michx.) was taken in North Carolina (fig. 1). The logs from all study trees were shipped to one sawmill and sawed into yard and structural lumber, and the yield of lumber by grade and width was recorded for each tree.

Both trial tree grading systems stratified the new sample into three distinct value classes, and again neither grading system was superior to the other. Since there was no difference in reliability between these systems, the clear-face tree grades were chosen because they are easier and cheaper to apply in the field than are knot-count grades.

The 1964 data were analyzed and combined with comparable data from the previous studies. Tables and equations presented in this report are based on the combined 1956, 1959, and 1964 study data.

Lumber grade-yields were analyzed separately by species. Because of similarities in yields, the species were combined into two groups: (1) loblolly, shortleaf, and pond pines; and (2) longleaf and slash pines.

Regression equations for lumber yield percentages by grade, as a function of tree diameter at breast height and merchantable tree height, were computed for each species group and clear-face tree grade. These equations are given in appendix tables 7 and 8. Mean lumber yield, standard errors, and correlation coefficients are given in appendix tables 9 and 10.

GRADING PROCEDURE

General

These tree grades apply to merchantable, standing loblolly, shortleaf, pond, longleaf, and slash pines. Trees are graded on the external characteristics of the butt 16-foot log in the tree. The number of clear faces, together with evaluation of the amount of sweep and/or rot, determines the tree grade. Trees must have a minimum diameter at breast height of 9.6 inches and a minimum merchantable height of two 16-foot logs to be considered under these rules.

One-log trees should be graded by the log grading system detailed in U.S.D.A. Forest Service Research Paper SE-39. This is recommended because the entire merchantable volume of the tree is contained in the graded section. The log grading system gives a more accurate prediction of the lumber grade-yields for such trees than would the tree grading system.

Trees with a net scale less than one-third of their gross scale will be classified "cull" under these tree or log grading rules.

Grading Rules

Trees are graded in three steps. First, determine the number of clear faces[1] on the butt 16-foot grading section. Usually the grading section is taken from a 12-inch stump height, but it can be moved up as high as 4 feet to avoid including a fire scar or similar defect in the grading section. Include as many defects as possible in one face so the maximum number of clear faces is obtained. If the grading section has three or more clear faces, classify it a tentative Grade A; if one or two clear faces, tentative Grade B; and if it has no clear face, tentative Grade C.

The second step is to examine the grading section for sweep. If sweep in the lower 12 feet of the grading section amounts to 3 inches or more and is equal to or greater than one-fourth the diameter at breast height, lower the grade of the tree one grade if it was tentative Grade A or B after the clear face examination. Tentative Grade C trees are dropped to cull if total scalable defect exceeds two-thirds the gross scale of the tree.

The third step in grading is to examine the entire tree for evidence of heart rot. If either conks, massed hyphae, or punk knots are found anywhere on the stem, reduce the tree one grade as was done for sweep. Tentative Grade C trees are dropped to cull if total scalable defect exceeds two-thirds the gross scale of the tree.

The grading procedure in abbreviated form is outlined below:

SOUTHERN PINE TREE GRADES

Grade A - trees with 3 or 4 clear faces (see footnote 1) on the 16-foot grading section.

Grade B - trees with 1 or 2 clear faces on the 16-foot grading section.

Grade C - trees with no clear faces on the 16-foot grading section.

After the tentative grade is established, the tree will be reduced one grade for each of the following:

(1) Sweep. Degrade any tentative Grade A or B tree one grade if sweep in the lower 12 feet of the grading sections amounts to 3 or more inches and equals or exceeds one-fourth the diameter at breast height.

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[1] A face is one-fourth the circumference of the 16-foot grading section and extends the full length of the grading section. Clear faces are those free from knots measuring more than $\frac{1}{2}$ inch in diameter, overgrown knots of any size, and holes more than $\frac{1}{4}$ inch in diameter. Faces may be rotated, if necessary, to obtain the maximum number of clear faces on the grading section.

(2) Heart rot. Degrade any tentative Grade A or B tree one grade if conks, punk knots, or other evidence of advanced heart rot is found anywhere on the tree stem.

NOTE: No tree can be degraded below Grade C, provided the total scaling deductions for sweep and/or rot do not exceed two-thirds the gross scale of the tree. Trees with total scaling deductions in excess of two-thirds gross scale are classified as cull.

The lumber grade-yields for the two species groups are presented in tables 1 through 6 by tree grade, height, and d. b. h. (In the tables, Grade 1D includes No. 1 dimension and No. 1 dense; Grade 2D includes No. 2 dimension, No. 2 dense, and "Special"; Grade 3D includes No. 3 dimension and No. 3 dense.) Two-inch diameter classes are given, but lumber yields for 1-inch or 3-inch or any other diameter class can be computed from the regression equations which were used to develop these tables.

DISCUSSION

Note that lumber yields in the tables are expressed on a rough-green basis. The many mills sampled in this study varied in the degree of finish manufacture (some sold rough-green lumber; some rough, air-dry; some surfaced air-dry; and some surfaced kiln-dry) so the rough-green lumber was the only basis at which comparisons of yields could be made. Furthermore, each stage of processing beyond the rough-green state results in some degrade due to manufacture, which is not related to the grade of the tree from which the lumber was cut. An individual using these grades will be in a position to estimate better his percentage of drying-surfacing degrade than he could with any average figures that might be included here.

The lumber grade-yields in the tables are South-wide averages. Any particular sawmill sawing for a product mix different from that which resulted in this study can expect to get lumber yields different from those shown in the tables. For example, if a mill is producing 90 percent of its lumber volume in dimension, it will obviously not get the board-dimension mix shown in the tables. In cases like this, it will be necessary for the mill to conduct its own mill-scale study. This can be easily done by grading the trees before they are sawed and making an aggregate lumber tally by grade, thickness, and width of the lumber produced from a sample of representative trees in each of the three tree grades.

These tree grades have been approved as standard by the Chief of the Forest Service for use in appraising standing southern pine sawtimber on National Forest timber sales. They are simple and easy to apply and will stratify trees into distinct value classes if the trees are carefully and accurately graded.

Table 1.--Lumber grade-yield for longleaf-slash pine

GRADE A, 2-LOG TREES

D. b. h.	B&B	C	D&1C	2C	3C	4C	1D	2D	3D	4D
Inches	Percent									
10	0	0	0	0	0	0	0	0	0	0
12	3	14	20	13	3	1	40	3	3	0
14	5	12	20	24	3	1	26	4	4	1
16	5	11	21	32	3	1	18	5	3	1
18	5	9	22	38	3	1	14	5	3	0
20	3	7	23	44	3	0	14	5	1	0
22	1	5	24	47	2	0	16	5	0	0
GRADE A, 3-LOG TREES										
10	0	0	0	0	0	0	0	0	0	0
12	5	10	22	9	0	0	47	7	0	0
14	8	10	22	18	2	0	31	8	1	0
16	8	10	22	25	2	0	23	8	2	0
18	9	11	22	29	2	0	18	7	2	0
20	7	11	23	33	2	0	17	6	1	0
22	6	11	23	36	2	0	17	5	0	0
24	4	10	24	37	2	0	20	3	0	0
26	1	9	25	39	1	0	23	2	0	0
GRADE A, 4-LOG TREES										
10	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0
14	10	8	23	12	0	0	37	10	0	0
16	12	10	23	17	1	0	27	10	0	0
18	12	12	22	21	1	0	22	9	1	0
20	12	14	22	23	2	0	19	7	1	0
22	11	16	22	24	2	0	19	5	1	0
24	10	18	23	24	2	0	20	3	0	0
26	8	20	23	24	2	0	23	0	0	0

Table 2. --Lumber grade-yield for longleaf-slash pine

GRADE B, 2-LOG TREES

D.b.h.	B&B	C	D&1C	2C	3C	4C	1D	2D	3D	4D
Inches	Percent									
10	3	7	24	21	0	0	38	7	0	0
12	3	10	20	29	0	0	27	11	0	0
14	4	11	18	34	1	0	19	13	0	0
16	5	12	17	37	2	0	14	13	0	0
18	7	11	17	39	3	0	11	12	0	0
20	9	10	16	40	5	0	9	11	0	0
22	11	9	17	40	6	0	8	9	0	0

GRADE B, 3-LOG TREES

10	0	0	0	0	0	0	0	0	0	0
12	3	9	22	25	0	0	31	9	1	0
14	4	10	20	30	1	0	23	11	1	0
16	5	11	19	33	2	0	18	11	1	0
18	7	10	19	35	3	0	15	10	1	0
20	9	10	19	35	5	0	13	9	0	0
22	11	9	19	36	6	0	12	7	0	0
24	14	7	19	36	8	0	11	5	0	0
26	16	5	20	36	9	0	11	3	0	0

GRADE B, 4-LOG TREES

10	0	0	0	0	0	0	0	0	0	0
12	3	8	22	21	1	1	31	11	2	0
14	3	10	20	26	1	1	24	13	2	0
16	5	10	19	29	2	1	19	13	2	0
18	7	9	18	31	4	1	16	12	2	0
20	9	9	18	32	5	1	13	11	2	0
22	11	8	19	33	6	1	12	9	1	0
24	14	6	19	33	8	0	12	7	1	0
26	16	5	20	32	9	0	12	5	1	0

Table 3.--Lumber grade-yield for longleaf-slash pine

GRADE C, 2-LOG TREES

D.b.h.	B&B	C	D&1C	2C	3C	4C	1D	2D	3D	4D
Inches	Percent									
10	2	6	17	31	0	0	32	11	1	0
12	2	6	16	39	0	0	23	14	0	0
14	1	6	16	45	1	0	16	15	0	0
16	1	6	15	50	2	0	11	14	1	0
18	1	6	13	54	4	0	7	12	3	0
20	1	6	11	57	6	0	4	9	6	0
22	1	6	9	59	9	0	2	5	9	0

GRADE C, 3-LOG TREES

D.b.h.	B&B	C	D&1C	2C	3C	4C	1D	2D	3D	4D
10	0	0	0	0	0	0	0	0	0	0
12	4	7	18	32	0	0	25	13	1	0
14	4	7	17	38	1	0	18	14	1	0
16	4	7	16	43	2	0	13	13	2	0
18	4	7	14	47	4	0	9	11	4	0
20	3	8	12	50	6	0	6	8	7	0
22	3	8	10	52	9	0	3	4	10	1
24	3	8	7	54	11	0	2	0	14	1

GRADE C, 4-LOG TREES

D.b.h.	B&B	C	D&1C	2C	3C	4C	1D	2D	3D	4D
10	0	0	0	0	0	0	0	0	0	0
12	7	8	22	21	0	0	23	19	0	0
14	6	8	21	27	0	0	17	21	0	0
16	6	8	20	32	2	0	11	20	1	0
18	6	8	18	36	3	0	7	18	4	0
20	6	8	16	39	6	0	4	15	6	0
22	6	8	14	41	8	0	2	10	10	1
24	5	9	11	43	11	0	0	6	14	1
26	5	9	8	45	14	0	0	0	18	1

Table 4. --Lumber grade-yield for loblolly-shortleaf-pond pine

GRADE A, 2-LOG TREES

D. b. h.	B&B	C	D&1C	2C	3C	4C	1D	2D	3D	4D
Inches	Percent									
10	3	4	12	11	2	1	53	11	2	1
12	7	7	15	16	2	1	35	14	2	1
14	11	7	16	19	3	1	23	16	3	1
16	12	7	16	21	5	1	13	18	6	1
18	14	6	16	22	7	1	6	19	8	1
20	14	4	15	23	10	1	1	20	11	1
22	14	2	12	23	12	2	0	20	14	1
GRADE A, 3-LOG TREES										
10	0	0	0	0	0	0	0	0	0	0
12	5	6	15	19	2	0	39	12	2	0
14	8	8	17	21	2	0	28	14	2	0
16	11	8	17	23	3	0	20	15	3	0
18	12	8	16	23	5	1	14	16	5	0
20	13	7	15	23	7	1	10	16	7	1
22	13	6	14	23	9	1	7	17	9	1
24	14	4	12	23	11	1	5	17	12	1
26	14	3	10	22	13	1	4	17	15	1
GRADE A, 4-LOG TREES										
10	0	0	0	0	0	0	0	0	0	0
12	3	5	15	21	0	0	43	11	2	0
14	6	8	16	23	0	0	34	12	1	0
16	9	9	17	24	1	0	27	12	1	0
18	10	10	17	24	2	0	23	13	1	0
20	11	10	16	24	4	0	20	13	2	0
22	12	10	15	23	5	1	18	12	4	0
24	12	9	13	22	7	1	18	12	5	1
26	12	9	12	21	9	1	17	11	7	1

Table 5. --Lumber grade-yield for loblolly-shortleaf-pond pine

GRADE B, 2-LOG TREES

D.b.h.	B&B	C	D&1C	2C	3C	4C	1D	2D	3D	4D
Inches					Percent					
10	2	2	11	20	4	0	30	27	4	0
12	4	4	14	23	2	0	27	23	3	0
14	6	4	15	25	2	1	23	20	4	0
16	7	4	16	27	4	1	18	17	6	0
18	9	3	15	28	7	2	13	14	8	1
20	10	2	14	30	11	2	7	12	11	1
22	12	1	14	31	16	2	0	9	13	2

GRADE B, 3-LOG TREES

10	0	0	0	0	0	0	0	0	0	0
12	4	3	15	20	3	1	27	22	5	0
14	5	4	16	22	2	1	25	20	5	0
16	[illegible]	5	16	23	3	1	22	19	5	0
18	7	5	16	24	5	1	18	18	7	0
20	8	5	13	25	8	1	14	17	8	1
22	9	5	11	26	12	1	9	16	10	1
24	10	4	10	26	14	2	4	16	12	2
26	11	3	7	27	19	2	0	15	14	2

GRADE B, 4-LOG TREES

10	0	0	0	0	0	0	0	0	0	0
12	5	1	17	18	4	0	27	20	7	1
14	5	4	17	19	2	0	26	21	6	0
16	6	6	16	19	2	0	25	21	5	0
18	6	7	14	20	3	0	23	22	5	0
20	6	8	12	20	5	0	20	23	6	0
22	[illegible]	9	9	20	7	1	18	24	6	0
24	7	9	6	20	10	1	15	25	7	0
26	7	9	4	20	13	1	12	26	8	0

Table 6. --Lumber grade-yield for loblolly-shortleaf-pond pine

GRADE C, 2-LOG TREES

D.b.h.	B&B	C	D&1C	2C	3C	4C	1D	2D	3D	4D
Inches	Percent									
10	0	1	8	18	3	0	29	24	15	2
12	2	2	12	24	1	0	21	24	13	1
14	3	2	12	28	2	0	16	23	13	0
16	3	3	12	29	4	0	13	22	14	0
18	4	3	10	30	7	0	10	20	16	0
20	5	3	7	29	10	0	10	18	18	0
22	5	3	4	28	14	0	9	16	21	0

GRADE C, 3-LOG TREES

D.b.h.	B&B	C	D&1C	2C	3C	4C	1D	2D	3D	4D
10	0	0	0	0	0	0	0	0	0	0
12	1	1	5	20	2	0	23	30	18	0
14	2	2	7	23	2	0	18	29	17	0
16	3	3	8	24	3	0	14	28	17	0
18	4	3	8	24	5	0	12	27	17	0
20	4	4	7	23	8	0	11	25	18	0
22	5	4	6	21	11	0	10	23	19	1
24	5	5	4	18	14	0	10	21	21	2
26	6	5	2	16	18	0	10	19	22	2

GRADE C, 4-LOG TREES

D.b.h.	B&B	C	D&1C	2C	3C	4C	1D	2D	3D	4D
10	0	0	0	0	0	0	0	0	0	0
12	0	0	0	15	2	0	14	35	24	0
14	1	2	2	17	2	0	19	36	21	0
16	2	3	5	18	2	0	15	35	20	0
18	3	4	7	17	4	0	13	33	19	0
20	4	5	8	15	5	0	12	32	18	1
22	4	6	8	13	8	0	11	30	18	2
24	5	7	8	10	10	0	10	28	18	4
26	6	7	8	7	13	0	10	26	18	5

Appendix

Table 7.--Regression equations for longleaf-slash pine

GRADE A TREES

Dependent variables					
Lumber grade	Constant	x D.b.h.	x Merch. ht.	x 1/D.b.h.	x Merch. ht. x D.b.h.
B&B	+0.83523	-0.03095	-0.00160	-5.58679	+0.00022
C	+0.68066	-0.03213	-0.00994	-0.85856	+0.00061
D&1C	-0.21876	+0.01807	+0.00385	+1.82271	-0.00020
2C	+0.66025	+0.01984	+0.00350	-8.19111	-0.00050
3C	+0.33629	-0.01025	-0.00259	-1.75412	+0.00011
4C	+0.16530	-0.00693	-0.00193	-0.53872	+0.00010
1D, 1 Dense	-2.44879	+0.07139	+0.00863	+22.13135	-0.00035
2D, 2 Dense, Spcl.	+0.25771	-0.00326	+0.00506	-3.25511	-0.00022
3D, 3 Dense	+0.56206	-0.01989	-0.00375	-2.90452	+0.00018
4D	+0.17010	-0.00590	-0.00123	-0.86536	+0.00005
GRADE B TREES					
B&B	-0.34950	+0.01617	+0.00010	+2.04163	+0.32799
C	+0.54736	-0.01339	-0.00042	-3.36798	+0.24220
D&1C	+0.03815	+0.00874	-0.00169	+3.15753	-4.97068
2C	+0.90253	-0.01185	-0.00120	-6.15087	+2.77624
3C	-0.21778	+0.00933	+0.00037	+0.94902	+0.62253
4C	-0.01937	-0.00088	+0.00064	-0.16090	+0.70899
1D, 1 Dense	-0.26608	+0.01258	-0.00223	+8.27701	-7.74202
2D, 2 Dense, Spcl.	+0.38255	-0.01953	+0.00362	-4.69444	+7.63482
3D, 3 Dense	-0.01784	-0.00118	+0.00082	-0.05111	+0.39988
4D	+0.00000	+0.00000	+0.00000	+0.00000	+0.00000
GRADE C TREES					
B&B	-0.00362	-0.00065	+0.00154	-0.01920	-0.03120
C	+0.12290	+0.00150	-0.00010	-0.03095	-1.55938
D&1C	-0.44471	-0.02288	+0.00391	+0.56068	+5.00411
2D	-0.36933	-0.01696	-0.00944	+1.41312	-8.34242
3C	+0.52488	+0.02870	-0.00050	-0.76715	-0.81889
4C	-0.03879	-0.00097	+0.00000	+0.04523	+0.08730
1D, 1 Dense	+2.17896	+0.02605	-0.00307	-1.80862	-6.80600
2D, 2 Dense, Spcl.	-1.96255	-0.06080	+0.00841	+1.96550	+14.29065
3D, 3 Dense	+0.94753	+0.04351	-0.00075	-1.28953	-1.78727
4D	+0.04479	+0.00250	+0.00001	-0.06914	-0.03704

Table 8.--Regression equations for loblolly-shortleaf-pond pine

GRADE A TREES

Dependent variables	Independent variables				
Lumber grade	Constant	x D.b.h.	x Merch. ht.	x 1/D.b.h.	x Merch. ht. x D.b.h.
B&B	+0.51638	-0.00802	-0.0196	-3.59237	+0.00005
C	+0.73120	-0.02879	-0.00401	-3.65041	+0.00030
D&1C	+0.69676	-0.01880	-0.00070	-3.83730	+0.00006
2C	+0.48710	-0.00311	+0.00325	-4.03172	-0.00015
3C	-0.42515	+0.02344	+0.00117	+2.27463	-0.00015
4C	-0.04924	+0.00307	+0.00005	+0.29286	-0.00002
1D, 1 Dense	-0.53710	-0.01033	-0.00271	+11.20363	+0.00043
2D, 2 Dense, Spcl.	+0.25520	+0.00568	+0.00110	-1.85011	-0.00017
3D, 3 Dense	-0.62746	+0.03485	+0.00398	+2.77240	-0.00034
4D	-0.04780	+0.00202	-0.00017	+0.41926	0.00000
GRADE B TREES					
B&B	-0.7534	+0.01173	+0.00223	-0.36326	-0.00017
C	+0.59577	-0.02437	-0.00456	-2.88373	+0.00032
D&1C	+0.44820	-0.00558	+0.00360	-3.25114	-0.00022
2C	+0.28899	+0.00897	+0.00059	-1.39363	-0.00018
3C	-0.99520	+0.04540	+0.00463	+5.32449	-0.00033
4C	-0.07943	+0.00507	+0.00072	+0.28973	-0.00006
1D, 1 Dense	+1.21854	-0.05725	-0.00702	-3.01622	+0.00057
2D, 2 Dense, Spcl.	+0.47855	-0.02702	-0.00720	+1.19022	+0.00054
3D, 3 Dense	-0.64166	+0.03227	+0.00512	+3.00691	-0.00033
4D	-0.23839	+0.01077	+0.00189	+1.09649	-0.00012
GRADE C TREES					
B&B	+0.10057	-0.00054	-0.00110	-0.67245	+0.00004
C	+0.17306	-0.00663	-0.00210	-0.74358	+0.00014
D&1C	+1.24465	-0.04585	-0.01107	-5.22907	+0.00056
2C	+1.00841	-0.01273	-0.00026	-6.26256	-0.00021
3C	-0.79729	+0.03679	+0.00325	+4.28043	-0.00024
4C	+0.03409	-0.00128	-0.00014	-0.16665	+0.00001
1D, 1 Dense	-0.57488	+0.01631	+0.00258	+6.49737	-0.00010
2D, 2 Dense, Spcl.	+0.48010	-0.01687	+0.00316	-1.94585	+0.00005
3D, 3 Dense	-0.70045	+0.03495	+0.00867	+3.53266	-0.00043
4D	+0.03176	-0.00415	-0.00300	+0.70960	+0.00017

Table 9.--Mean lumber yield, standard errors, and correlation coefficients for longleaf-slash pine

GRADE A TREES (Basis: 102 trees)

Lumber grade	Mean lumber yield Percent	Standard error of the mean Percent	Multiple R
B&B	7.379	.618	.519
C	10.719	.704	.265
D&1C	21.510	1.009	.093
2C	21.912	1.577	.614
3C	1.812	.318	.331
4C	.531	.209	.200
1D, 1 Dense	28.061	1.673	.781
2D, 2 Dense, Spcl.	6.587	.854	.267
3D, 3 Dense	1.241	.369	.330
4D	.247	.235	.185

GRADE B TREES (Basis: 89 trees)

Lumber grade	Mean lumber yield Percent	Standard error of the mean Percent	Multiple R
B&B	4.400	.530	.335
C	9.806	.654	.281
D&1C	19.681	1.116	.272
2C	30.186	1.740	.389
3C	1.711	.359	.374
4C	.171	.069	.425
1D, 1 Dense	22.673	1.762	.571
2D, 2 Dense, Spcl.	10.656	1.157	.270
3D, 3 Dense	.716	.350	.187
4D	--	--	--

GRADE C TREES (Basis: 121 trees)

Lumber grade	Mean lumber yield Percent	Standard error of the mean Percent	Multiple R
B&B	2.344	.342	.415
C	5.830	.557	.286
D&1C	16.924	1.171	.246
2C	37.339	1.744	.563
3C	1.131	.264	.641
4C	.123	.075	.151
1D, 1 Dense	19.750	1.564	.492
2D, 2 Dense, Spcl.	15.266	1.433	.426
3D, 3 Dense	1.236	.433	.447
4D	.057	.057	.243

Table 10. --Mean lumber yield, standard errors, and correlation coefficients for loblolly-shortleaf-pond pine

GRADE A TREES (Basis: 241 trees)

Lumber grade	Mean lumber yield	Standard error of the mean	Multiple R
	Percent	Percent	
B&B	10.445	.506	.379
C	7.470	.429	.273
D&1C	15.255	.558	.209
2C	21.849	.678	.297
3C	4.236	.370	.515
4C	.810	.170	.166
1D, 1 Dense	20.962	1.112	.700
2D, 2 Dense, Spcl.	14.285	.782	.178
3D, 3 Dense	4.331	.481	.436
4D	.357	.119	.165
GRADE B TREES (Basis: 167 trees)			
B&B	5.760	.546	.336
C	4.440	.410	.402
D&1C	13.552	.817	.300
2C	22.250	.964	.233
3C	4.780	.527	.539
4C	.740	.192	.182
1D, 1 Dense	21.558	1.304	.423
2D, 2 Dense, Spcl.	20.707	1.431	.243
3D, 3 Dense	5.756	.672	.248
4D	.457	.155	.285
GRADE C TREES (Basis: 116 trees)			
B&B	2.218	.357	.428
C	2.595	.352	.372
D&1C	8.867	.870	.326
2C	20.302	1.588	.377
3C	4.706	.723	.438
4C	.599	.140	.125
1D, 1 Dense	19.784	2.157	.439
2D, 2 Dense, Spcl.	24.332	1.705	.267
3D, 3 Dense	15.431	1.927	.148
4D	1.175	.879	.226

U.S.D.A. Forest Service Research Paper SE-41 September 1968

SOUTHERN YELLOW PINE TREE OVERRUNS AND LUMBER WIDTH DISTRIBUTIONS

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This is one of a group of four publications by the Southeastern Forest Experiment Station pertaining to southern pine log and tree grade lumber recovery studies. The four publications are:

Southern Pine Log Grades for Yard and Structural Lumber, U.S.D.A. Forest Service Research Paper SE-39, by J. G. Schroeder, R. A. Campbell, and R. C. Rodenbach.

Southern Pine Tree Grades for Yard and Structural Lumber, U.S.D.A. Forest Service Research Paper SE-40, by J. G. Schroeder, R. A. Campbell, and R. C. Rodenbach.

Combined Effects of Drying, Surfacing, and Trimming on Grade and Volume of Southern Pine Lumber, U.S.D.A. Forest Service Research Note SE-93, by B. E. Carpenter, Jr., and J. G. Schroeder.

Southern Yellow Pine Tree Overruns and Lumber Distributions, U.S.D.A. Forest Service Research Paper SE-41, by D. O. Yandle.

SOUTHERN YELLOW PINE TREE OVERRUNS AND LUMBER WIDTH DISTRIBUTIONS

by

David O. Yandle

Overruns and underruns were calculated and board widths summarized from data collected in southern yellow pine sawing studies conducted in 1956, 1959, and 1964, at six mills in the South and Southeast. These studies included trees of the following species: Loblolly (Pinus taeda L.), shortleaf (P. echinata Mill.), pond (P. serotina Michx.), longleaf (P. palustris Mill.), and slash (P. elliottii Engelm.) pine. The data from the three studies were pooled for analysis, and the combined results are presented in this paper.

Sample trees selected in the woods were felled, bucked into logs, and shipped to the mill where they were subsequently sawed into lumber. By careful tagging and marking at each step throughout all studies, it was possible to identify each board with the tree from which it was taken.

All trees were graded by the clear-face system, which is approved by the Forest Service as its standard grading method for southern pine sawtimber. The 1964 study trees were graded standing and also from diagrams made after felling, and a comparison showed no substantial differences in the two methods of grading. Because the present tree grades were not yet developed at the time the 1956 and 1959 studies were made, trees from those studies were graded from diagrams made at the time they were felled.

At each of the study mills, the logs were sawed into yard and structural lumber and the grade, width, length, and thickness recorded for each board. Because the individual mills varied in subsequent processing and drying practices, rough-green lumber was the only common basis for combining yield data from all mills. All results in this paper are on the rough-green basis. Headsaws generally had $\frac{1}{4}$-inch saw kerf, but some mills had band re-saws, so saw kerf was a variable not measured.

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TREE OVERRUNS

Overruns or underruns were calculated for each study tree by combining data for all logs in the tree. The individual logs were scaled by each of the three log rules: Doyle, Scribner Decimal C, and International $\frac{1}{4}$-inch. For a given log scale, the actual tree overrun or underrun is the difference between the total lumber tally volume, V, produced from the tree and the sum, S, of the log scale volume for all logs in the tree. The percent overrun or underrun for the tree is:

$$\text{tree percent overrun} = \frac{V-S}{S} \times 100$$

This method does not give the same overruns as would be obtained if the estimated scale came from a tree volume table. Overruns would differ for each different tree volume table; and because there are many such tables commonly in use for southern pine throughout the South and Southeast, it was felt that computing tree overruns on the familiar log scales would provide a more common base for use of the table.

The tree percent overruns were plotted against diameter at breast height (d.b.h.) for each of the three log rules, and regression equations were fitted to these data. For each d.b.h. within the range of the data, the overruns calculated from these equations are given in table 1.

Table 1.--Tree overrun by d.b.h. classes[1]

Tree d.b.h. (inches)	Trees measured	Log rule		
		Doyle	Scribner Decimal C	International $\frac{1}{4}$-inch
	Number	Percent overrun		
8	21	296	9	-11
9	22	214	11	-10
10	46	160	12	- 9
11	49	123	13	- 8
12	55	97	13	- 7
13	66	78	14	- 6
14	91	63	14	- 5
15	73	52	14	- 5
16	67	44	14	- 4
17	77	37	13	- 4
18	54	32	13	- 4
19	62	27	12	- 4
20	41	24	11	- 4
21	33	21	9	- 4
22	25	18	8	- 4
23	17	16	6	- 5
24	10	14	4	- 5
25	7	13	2	- 6
26	5	11	- 1	- 6
27	4	10	- 3	- 7
Total	825			

[1] The prediction equations are:

$$\text{Doyle overrun } (\%) = e^{4.96305 - 2.7588 \log_{10}(\text{d.b.h.})}$$

$$\text{Scribner overrun } (\%) = -9.4687 + 3.2548(\text{d.b.h.}) - 0.11217(\text{d.b.h.})^2$$

$$\text{International overrun } (\%) = -25.566 + 2.2969(\text{d.b.h.}) - 0.060164(\text{d.b.h.})^2$$

Trees of all three grades were combined for determining the overrun equations. Merchantable height was included in the initial equations; however, it was not significant and was dropped from the final percent overrun equations given with table 1. Actual overruns would, of course, be related to merchantable height since, for a given d.b.h., volume increases with increasing merchantable height.

As shown in table 1, tree overrun percents based on all three log rules are quite similar to log overruns for southern yellow pine logs.[1] The differences in tree and log overrun percents are due primarily to two reasons: First, the effect of combining log volume, for logs having different volume and different overrun percents, in order to calculate the tree overrun; and second, the indexing of the tree overrun table by tree d.b.h., whereas log overruns are indexed by diameter inside bark (d.i.b.) at the small end of the log.

LUMBER WIDTH DISTRIBUTION

Because lumber prices are quite different for different board widths, it is of considerable interest to know the distribution by widths of the lumber in each lumber grade.

Tables 2-19 give the distribution by board width in each lumber grade for each of the three tree grades, for all three tree grades combined, and for d.b.h. classes 10, 13, 16, 19, and 22+ inches.[2]

These tables present actual yield data--not curved data--for the 157,769 board feet of rough-green lumber manufactured in all three studies. Of the total lumber in the studies, 96,108 board feet, or 61 percent, was in boards and 61,661 board feet, or 39 percent, was in dimension. It should be recognized that these data represent a southwide average for mills that are average or better than average in mill alignment and manufacturing practices. A mill that produces substantially different proportions of boards and dimension would not necessarily produce the same percentage distribution of lumber widths.

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[1] Rodenbach, Richard C. Southern yellow pine log overruns. Southeast. Forest Exp. Sta., U. S. Forest Serv. Res. Note SE-56, 2 pp. 1966.

[2] The d.b.h. classes are: 10-inch class = 9.0-11.9 inches, 13-inch class = 12.0-14.9 inches, etc.

Table 2.--Distribution of lumber, by lumber grades and board widths--tree grade A, d.b.h. class 10

Board width (inches)	Lumber grade (boards)[1/]						Lumber grade (dimension)[2/]				All grades	Total lumber
	B and bet.	C sel.	D sel. and 1 com.	2 com.	3 com.	4 com.	1 dim. and 1 den.	2 dim. and 2 den.	3 dim. and 3 den.	4 dim.		
	Percent											Board feet
3	5	18	6	18	0	23	0	0	0	0	5	142
4	55	52	36	43	100	77	23	42	0	100	33	1,027
5	19	8	10	10	0	0	0	0	0	0	4	124
6	21	22	43	21	0	0	73	44	100	0	52	1,608
8	0	0	5	4	0	0	4	14	0	0	5	147
10	0	0	0	0	0	0	0	0	0	0	0	0
12+	0	0	0	4	0	0	0	0	0	0	1	16
	Board feet											
Total lumber	84	207	553	369	33	9	1,471	285	30	23	--	3,064

[1/] Total volume in boards = 1,255 board feet, or 41 percent.
[2/] Total volume in dimension = 1,809 board feet, or 59 percent.

Table 3.--Distribution of lumber, by lumber grades and board widths--tree grade A, d.b.h. class 13

Board width (inches)	Lumber grade (boards)[1/]						Lumber grade (dimension)[2/]				All grades	Total lumber
	B and bet.	C sel.	D sel. and 1 com.	2 com.	3 com.	4 com.	1 dim. and 1 den.	2 dim. and 2 den.	3 dim. and 3 den.	4 dim.		
	Percent											Board feet
3	5	6	3	6	7	18	0	0	0	0	3	271
4	27	18	16	26	16	35	2	6	23	0	13	1,289
5	25	15	7	11	14	0	0	1	0	0	7	664
6	33	37	43	34	20	19	58	57	50	100	46	4,477
8	10	24	30	23	43	28	40	36	27	0	31	2,936
10	0	0	0	0	0	0	0	0	0	0	0	0
12+	0	0	1	0	0	0	0	0	0	0	0	12
	Board feet											
Total lumber	660	880	1,853	1,795	157	38	3,150	891	157	68	--	9,649

[1/] Total volume in boards = 5,383 board feet, or 56 percent.
[2/] Total volume in dimension = 4,266 board feet, or 44 percent.

Table 4.--Distribution of lumber, by lumber grades and board widths--tree grade A, d.b.h. class 16

Board width (inches)	Lumber grade (boards)[1]						Lumber grade (dimension)[2]				All grades	Total lumber
	B and bet.	C sel.	D sel. and 1 com.	2 com.	3 com.	4 com.	1 dim. and 1 den.	2 dim. and 2 den.	3 dim. and 3 den.	4 dim.		
	Percent											Board feet
3	1	2	2	1	2	9	0	0	0	0	1	173
4	12	8	6	11	16	49	2	1	0	0	7	1,255
5	11	9	4	7	4	0	0	0	0	0	4	812
6	38	32	23	31	24	18	23	35	27	0	29	5,168
8	35	38	55	43	46	24	58	58	59	100	49	8,888
10	3	9	10	7	8	0	16	6	14	0	9	1,637
12+	0	2	0	0	0	0	1	0	0	0	1	89
	Board feet											
Total lumber	1,534	1,852	3,286	4,700	507	91	3,569	1,925	481	77	--	18,022

[1] Total volume in boards = 11,970 board feet, or 66 percent.
[2] Total volume in dimension = 6,052 board feet, or 34 percent.

Table 5.--Distribution of lumber, by lumber grades and board widths--tree grade A, d.b.h. class 19

Board width (inches)	Lumber grade (boards)[1]						Lumber grade (dimension)[2]				All grades	Total lumber
	B and bet.	C sel.	D sel. and 1 com.	2 com.	3 com.	4 com.	1 dim. and 1 den.	2 dim. and 2 den.	3 dim. and 3 den.	4 dim.		
	Percent											Board feet
3	0	1	1	1	1	2	0	0	0	0	1	118
4	5	5	4	7	11	17	0	0	1	45	4	927
5	7	8	3	4	4	7	0	0	0	0	3	770
6	23	24	15	18	26	15	7	11	8	0	16	3,528
8	36	38	42	44	25	52	50	54	67	55	45	10,119
10	23	12	25	22	24	7	39	29	21	0	25	5,726
12+	6	12	10	4	9	0	4	6	3	0	6	1,462
	Board feet											
Total lumber	2,400	2,143	4,233	5,430	915	144	3,799	2,449	1,028	109	--	22,650

[1] Total volume in boards = 15,265 board feet, or 67 percent.
[2] Total volume in dimension = 7,385 board feet, or 33 percent.

Table 6.--Distribution of lumber, by lumber grades and board widths--tree grade A, d.b.h. class 22+

Board width (inches)	Lumber grade (boards)[1]						Lumber grade (dimension)[2]				All grades	Total lumber
	B and bet.	C sel.	D sel. and 1 com.	2 com.	3 com.	4 com.	1 dim. and 1 den.	2 dim. and 2 den.	3 dim. and 3 den.	4 dim.		
	Percent											Board feet
3	0	0	0	0	0	0	0	0	0	0	C	27
4	6	3	4	4	9	12	0	1	1	6	4	1,164
5	6	4	4	3	5	5	0	0	0	0	3	880
6	18	18	12	11	14	9	1	4	9	37	10	3,233
8	35	29	27	25	21	9	26	16	23	17	25	7,550
10	21	22	18	25	18	24	53	42	33	7	28	8,738
12+	14	24	35	32	33	41	20	37	34	33	30	9,172
	Board feet											
Total lumber	3,757	1,894	3,962	7,000	3,016	494	2,737	4,636	2,791	477	--	30,764

[1] Total volume in boards = 20,123 board feet, or 65 percent.
[2] Total volume in dimension = 10,640 board feet, or 35 percent.

Table 7.--Distribution of lumber, by lumber grades and board widths--tree grade B, d.b.h. class 10

Board width (inches)	Lumber grade (boards)[1]						Lumber grade (dimension)[2]				All grades	Total lumber
	B and bet.	C sel.	D sel. and 1 com.	2 com.	3 com.	4 com.	1 dim. and 1 den.	2 dim. and 2 den.	3 dim. and 3 den.	4 dim.		
	Percent											Board feet
3	9	7	10	8	0	0	0	0	0	0	4	116
4	61	42	39	52	43	25	29	63	30	0	43	1,384
5	20	8	12	3	26	0	0	0	0	0	4	134
6	10	31	36	30	12	75	67	34	56	100	44	1,434
8	0	12	3	7	19	0	4	3	14	0	5	160
10	0	0	0	0	0	0	0	0	0	0	0	0
12+	0	0	0	0	0	0	0	0	0	0	0	0
	Board feet											
Total lumber	113	139	545	570	57	11	1,035	569	150	39	--	3,228

[1] Total volume in boards = 1,435 board feet, or 44 percent.
[2] Total volume in dimension = 1,793 board feet, or 56 percent.

Table 8.--Distribution of lumber, by lumber grades and board widths--tree grade B, d.b.h. class 13

Board width (inches)	Lumber grade (boards)[1/]						Lumber grade (dimension)[2/]				All grades	Total lumber
	B and bet.	C sel.	D sel. and 1 com.	2 com.	3 com.	4 com.	1 dim. and 1 den.	2 dim. and 2 den.	3 dim. and 3 den.	4 dim.		
	Percent											Board feet
3	3	3	1	3	7	10	0	0	0	0	1	108
4	36	28	20	30	48	[illegible]	2	9	13	0	19	1,444
5	10	13	5	3	0	20	0	0	0	0	4	263
6	29	44	47	48	21	6	59	74	75	0	52	3,974
8	22	12	27	16	24	0	39	17	12	0	24	1,788
10	0	0	0	0	0	0	0	0	0	0	0	0
12+	0	0	0	0	0	0	0	0	0	0	0	0
	Board feet											
Total lumber	354	583	1,515	2,067	117	34	1,813	919	135	40	—	7,577

1/ Total volume in boards = 4,670 board feet, or 62 percent.
2/ Total volume in dimension = 2,907 board feet, or 38 percent.

Table 9.--Distribution of lumber, by lumber grades and board widths--tree grade B, d.b.h. class 16

Board width (inches)	Lumber grade (boards)[1/]						Lumber grade (dimension)[2/]				All grades	Total lumber
	B and bet.	C sel.	D sel. and 1 com.	2 com.	3 com.	4 com.	1 dim. and 1 den.	2 dim. and 2 den.	3 dim. and 3 den.	4 dim.		
	Percent											Board feet
3	1	2	1	1	2	7	0	0	0	0	1	105
4	19	11	8	13	23	14	1	2	14	27	9	1,296
5	16	9	7	4	7	0	0	0	0	0	4	567
6	45	38	29	34	21	35	25	29	49	73	32	4,528
8	19	37	49	44	28	5	59	57	22	0	46	6,459
10	0	3	6	4	14	39	15	12	13	0	8	1,126
12+	0	0	0	0	5	0	0	0	2	0	0	41
	Board feet											
Total lumber	572	1,128	2,410	4,262	554	103	2,239	2,133	575	146	--	14,122

1/ Total volume in boards = 9,029 board feet, or 64 percent.
2/ Total volume in dimension = 5,093 board feet, or 36 percent.

Table 10.--Distribution of lumber, by lumber grades and board widths--tree grade B, d.b.h. class 19

Board width (inches)	Lumber grade (boards)[1/]						Lumber grade (dimension)[2/]				All grades	Total lumber
	B and bet.	C sel.	D sel. and 1 com.	2 com.	3 com.	4 com.	1 dim. and 1 den.	2 dim. and 2 den.	3 dim. and 3 den.	4 dim.		
	Percent											Board feet
3	0	1	1	0	1	4	0	0	0	0	0	67
4	9	7	5	9	12	11	1	1	1	62	5	877
5	8	6	3	4	3	7	0	0	0	0	3	428
6	25	24	15	21	17	8	4	12	19	38	16	2,653
8	36	38	41	39	26	41	37	52	43	0	40	6,822
10	16	19	27	21	29	29	55	32	34	0	31	5,272
12+	6	5	8	6	12	0	3	3	3	0	5	901
	Board feet											
Total lumber	1,158	1,276	2,383	3,847	1,040	91	3,170	2,819	983	253	--	17,020

1/ Total volume in boards = 9,795 board feet, or 58 percent.
2/ Total volume in dimension = 7,225 board feet, or 42 percent.

Table 11.--Distribution of lumber, by lumber grades and board widths--tree grade C, d.b.h. class 10

Board width (inches)	Lumber grade (boards)[1/]						Lumber grade (dimension)[2/]				All grades	Total lumber
	B and bet.	C sel.	D sel. and 1 com.	2 com.	3 com.	4 com.	1 dim. and 1 den.	2 dim. and 2 den.	3 dim. and 3 den.	4 dim.		
	Percent											Board feet
3	3	6	6	7	9	0	0	0	0	0	3	100
4	50	66	40	59	91	100	24	67	47	0	46	1,594
5	[illegible]	0	7	10	0	0	0	0	0	0	4	126
6	[illegible]	28	47	24	0	0	68	33	53	0	45	1,574
8	0	0	0	0	0	0	8	0	0	0	2	85
10	17	0	0	0	0	0	0	0	0	0	[illegible]	13
12+	0	0	0	0	0	0	0	0	0	0	0	0
	Board feet											
Total lumber	76	114	600	852	21	[illegible]	1,123	507	144	49	--	3,492

1/ Total volume in boards = 1,669 board feet, or 48 percent.
2/ Total volume in dimension = 1,823 board feet, or 52 percent.

Table 12.--Distribution of lumber, by lumber grades and board widths--tree grade C, d.b.h. class 13

Board width (inches)	Lumber grade (boards)[1]						Lumber grade (dimension)[2]				All grades	Total lumber
	B and bet.	C sel.	D sel. and 1 com.	2 com.	3 com.	4 com.	1 dim. and 1 den.	2 dim. and 2 den.	3 dim. and 3 den.	4 dim.		
	Percent											Board feet
3	8	2	3	2	4	29	0	0	0	0	1	146
4	69	31	21	29	40	45	3	13	15	0	20	2,212
5	0	8	6	5	3	0	0	0	0	0	3	317
6	23	45	39	44	37	26	45	59	60	100	48	5,134
8	0	14	31	20	16	0	52	28	25	0	28	3,007
10	0	0	0	0	0	0	0	0	0	0	0	0
12+	0	0	0	0	0	0	0	0	0	0	0	0
	Board feet											
Total lumber	205	556	1,403	3,552	180	54	1,829	1,956	878	203	--	10,816

[1] Total volume in boards = 5,950 board feet, or 55 percent.
[2] Total volume in dimension = 4,866 board feet, or 45 percent.

Table 13.--Distribution of lumber, by lumber grades and board widths--tree grade C, d.b.h. class 16

Board width (inches)	Lumber grade (boards)[1]						Lumber grade (dimension)[2]				All grades	Total lumber
	B and bet.	C sel.	D sel. and 1 com.	2 com.	3 com.	4 com.	1 dim. and 1 den.	2 dim. and 2 den.	3 dim. and 3 den.	4 dim.		
	Percent											Board feet
3	0	1	0	0	2	0	0	0	0	0	0	25
4	25	17	12	14	32	45	1	1	3	0	10	991
5	1	6	4	2	0	0	0	0	0	0	1	152
6	44	45	34	30	33	0	11	34	60	100	32	3,323
8	30	31	42	43	26	55	63	36	24	0	41	4,213
10	0	0	8	11	7	0	22	29	13	0	15	1,517
12+	0	0	0	0	0	0	3	0	0	0	1	59
	Board feet											
Total lumber	259	609	1,023	3,934	338	19	1,337	1,909	783	69	--	10,280

[1] Total volume in boards = 6,182 board feet, or 60 percent.
[2] Total volume in dimension = 4,098 board feet, or 40 percent.

Table 14.--Distribution of lumber, by lumber grades and board widths--tree grade C, d.b.h. class 19

Board width (inches)	Lumber grade (boards)[1]						Lumber grade (dimension)[2]				All grades	Total lumber
	B and bet.	C sel.	D sel. and 1 com.	2 com.	3 com.	4 com.	1 dim. and 1 den.	2 dim. and 2 den.	3 dim. and 3 den.	4 dim.		
	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	Percent	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	Board feet
3	0	0	0	0	1	0	0	0	0	0	0	4
4	7	11	8	12	28	39	0	1	2	0	7	474
5	0	9	3	2	1	0	0	0	0	0	1	86
6	48	35	26	24	28	7	5	9	31	0	20	1,427
8	40	34	53	46	34	54	22	20	40	0	35	2,456
10	5	11	10	16	8	0	73	70	22	100	37	2,592
12+	0	0	0	0	0	0	0	0	5	0	0	42
	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	Board feet	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -
Total lumber	188	324	649	1,832	328	61	958	1,760	955	26	--	7,081

[1] Total volume in boards = 3,382 board feet, or 48 percent.
[2] Total volume in dimension = 3,699 board feet, or 52 percent.

Table 15.--Distribution of lumber, by lumber grades and board widths--all tree grades combined, d.b.h. class 10

Board widths (inches)	Lumber grade (boards)[1]						Lumber grade (dimension)[2]				All grades	Total lumber
	B and bet.	C sel.	D sel. and 1 com.	2 com.	3 com.	4 com.	1 dim. and 1 den.	2 dim. and 2 den.	3 dim. and 3 den.	4 dim.		
	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	Percent	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	Board feet
3	6	12	7	9	2	8	0	0	0	0	4	358
4	56	52	38	53	69	60	25	60	35	36	41	4,005
5	14	6	10	8	13	0	0	0	0	0	4	384
6	19	26	42	26	6	32	70	36	58	64	47	4,617
8	0	4	3	3	10	0	5	4	7	0	4	392
10	5	0	0	0	0	0	0	0	0	0	0	13
12+	0	0	0	1	0	0	0	0	0	0	0	16
	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	Board feet	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -
Total lumber	273	461	1,698	1,790	112	25	3,629	1,361	325	111	--	9,785

[1] Total volume in boards = 4,359 board feet, or 45 percent.
[2] Total volume in dimension = 5,426 board feet, or 55 percent.

Table 16.--Distribution of lumber, by lumber grades and board widths--all tree grades combined, d.b.h. class 13

Board widths (inches)	Lumber grade (boards)[1]						Lumber grade (dimension)[2]				All grades	Total lumber
	B and bet.	C sel.	D sel. and 1 com.	2 com.	3 com.	4 com.	1 dim. and 1 den.	2 dim. and 2 den.	3 dim. and 3 den.	4 dim.		
	Percent											Board feet
3	5	4	2	3	6	21	0	0	0	0	2	526
4	37	25	19	29	34	49	2	11	16	0	18	4,945
5	17	12	6	6	6	5	0	0	0	0	4	1,244
6	30	41	44	43	27	17	55	62	60	100	48	13,585
8	11	18	29	19	27	8	43	27	24	0	28	7,731
10	0	0	0	0	0	0	0	0	0	0	0	0
12+	0	0	0	0	0	0	0	0	0	0	0	12
	Board feet											
Total lumber	1,218	2,019	4,772	7,414	454	127	6,793	3,765	1,170	311	--	28,043

[1] Total volume in boards = 16,004 board feet, or 57 percent.
[2] Total volume in dimension = 12,039 board feet, or 43 percent.

Table 17.--Distribution of lumber, by lumber grades and board widths--all tree grades combined, d.b.h. class 16

Board widths (inches)	Lumber grade (boards)[1]						Lumber grade (dimension)[2]				All grades	Total lumber
	B and bet.	C sel.	D sel. and 1 com.	2 com.	3 com.	4 com.	1 dim. and 1 den.	2 dim. and 2 den.	3 dim. and 3 den.	4 dim.		
	Percent											Board feet
3	1	2	1	1	2	7	0	0	0	0	1	303
4	15	10	8	12	23	32	2	1	5	12	8	3,542
5	11	9	5	4	4	0	0	0	0	0	4	1,532
6	41	36	27	32	25	24	21	33	48	42	31	13,019
8	30	37	51	44	34	18	59	50	33	46	46	19,561
10	2	5	8	7	10	19	17	16	13	0	10	4,280
12+	0	1	0	0	2	0	1	0	1	0	0	188
	Board feet											
Total lumber	2,364	3,590	6,719	12,895	1,399	212	7,146	5,967	1,840	293	--	42,425

[1] Total volume in boards = 27,179 board feet, or 64 percent.
[2] Total volume in dimension = 15,246 board feet, or 36 percent.

Table 18.--Distribution of lumber, by lumber grades and board widths--all tree grades combined, d.b.h. class 19

Board widths (inches)	Lumber grade (boards)[1/]						Lumber grade (dimension)[2/]				All grades	Total lumber
	B and bet.	C sel.	D sel. and 1 com.	2 com.	3 com.	4 com.	1 dim. and 1 den.	2 dim. and 2 den.	3 dim. and 3 den.	4 dim.		
	Percent											Board feet
3	0	1	1	0	1	2	0	0	0	0	0	190
4	6	6	5	8	14	20	0	1	1	34	5	2,279
5	7	7	3	4	3	6	0	0	0	0	3	1,284
6	25	25	16	20	22	11	5	11	19	10	16	7,608
8	36	37	42	43	27	49	42	44	50	21	42	19,397
10	20	15	24	21	24	12	50	40	26	35	29	13,589
12+	6	9	9	4	9	0	3	4	4	0	5	2,405
	Board feet											
Total lumber	3,747	3,743	7,265	11,108	2,283	297	7,927	7,028	2,966	388	--	46,752

1/ Total volume in boards = 28,443 board feet, or 61 percent.
2/ Total volume in dimension = 18,309 board feet, or 39 percent.

Table 19.--Distribution of lumber, by lumber grades and board widths--all tree grades combined, d.b.h. class 22+

Board widths (inches)	Lumber grade (boards)[1/]						Lumber grade (dimension)[2/]				All grades	Total lumber
	B and bet.	C sel.	D sel. and 1 com.	2 com.	3 com.	4 com.	1 dim. and 1 den.	2 dim. and 2 den.	3 dim. and 3 den.	4 dim.		
	Percent											Board feet
3	0	0	0	0	0	0	0	0	0	0	0	27
4	6	3	3	4	9	12	0	1	1	6	4	1,164
5	6	4	4	3	5	5	0	0	0	0	3	880
6	18	18	12	11	14	9	1	4	9	37	10	3,233
8	35	29	28	25	21	9	26	16	23	17	25	7,550
10	21	22	18	25	18	24	53	42	33	7	28	8,738
12+	14	24	35	32	33	41	20	37	34	33	30	9,172
	Board feet											
Total lumber	3,757	1,894	3,962	7,000	3,016	494	2,737	4,636	2,791	477	--	30,764

1/ Total volume in boards = 20,123 board feet, or 65 percent.
2/ Total volume in dimension = 10,641 board feet, or 35 percent.

Pilot Test of Sampling Procedures for Estimating Recreation Use on Winter-Sports Sites

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Cover—*Special treatment of this photo, showing a comely village resident gathering data and distributing post card questionnaires for a 1966-67 study of recreation use at the Brighton Winter-Sports Site in the Wasatch National Forest, Utah.*

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Asheville, North Carolina

Pilot Test of Sampling Procedures for Estimating Recreation Use on Winter-Sports Sites

by

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Principal Recreation Specialist

A unique sampling problem associated with estimating recreation use on winter-sports sites is obtaining a reliable estimate of amount of skiing. Because of large size and mountainous terrain of most winter-sports sites, only a fraction of total skiing can be seen at any one time from a single observation point. It is unlikely that an instantaneous count could be made of all skiers using an area even if several observation points were manned simultaneously. Other activities, such as snow play, sledding, and tobogganing, are quite easily sampled using an observational sampling technique. To estimate skiing use, however, a technique other than one based on direct observation must be employed.

In an effort to provide recreation managers and planners with a useful and inexpensive sampling procedure for estimating use on winter-sports sites, a pilot study was made during the 1966-67 winter use season. The area selected was the Brighton Winter-Sports Site located in the Wasatch National Forest, Utah. It is 25 miles from Salt Lake City and lies at 8,500 to 10,700 feet elevation. Brighton features one single- and two double-chair lifts. Three expert, three intermediate, and five novice ski runs are in use. The normal season of operation is mid-November to May. Lifts generally operate from 9:30 a.m. to 4:30 p.m. daily, depending on weather conditions and volume of use. Other facilities include two dining rooms, a cafeteria, rental cabins, and motel accommodations (fig. 1).

Techniques and Procedures

The sampling study covered the period November 23, 1966 through March 31, 1967. The recreation use season of 129 days was sampled on 18 randomly selected days, divided equally between weekdays and weekend holidays. Because of expected heavy use during school vacations, several of these days were added to the weekend/holiday stratum. The additional days included November 25; December 26, 27, 28, 29, and 30; January 2; and March 24 and 27. Each sample day was 7-1/2 hours—from 9 a.m. to 4:30 p.m.

Data were collected by a Brighton area resident on a contract basis. To obtain information necessary to generate use estimates, the observer made four complete circuits (sampling rounds) of the base area and a day-end traffic count on each of the 18 sample days. The first 15-minute period of each sampling round was spent at the site entrance recording number of persons per vehicle. The

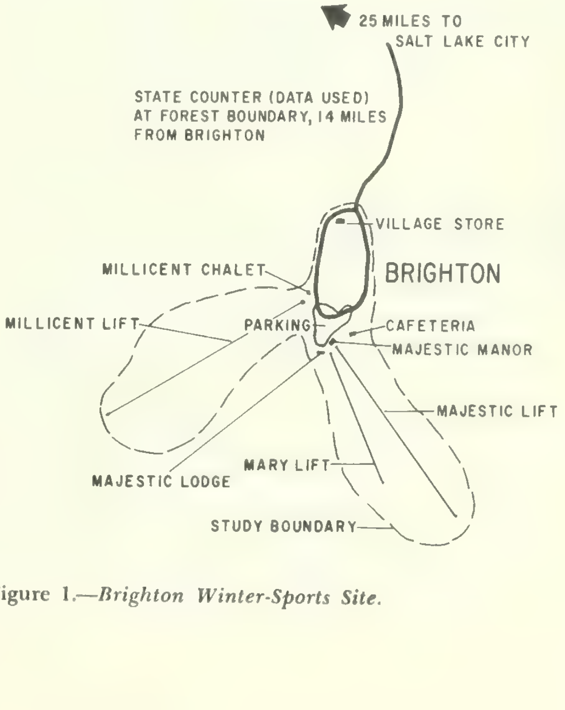

Figure 1.—*Brighton Winter-Sports Site.*

observer then made a circuit of the base area to gather other data. To avoid personal bias in circulating around the base area from one sampling round to the next, the observer developed a definite route which was followed throughout the entire sampling period. The route included all snow-play areas, eating places, lodge, equipment-rental shop, parking lot, and roads. The people associated with each major use of the site were counted. Vehicles belonging to Brighton Winter-Sports Site workers and other known nonrecreation vehicles were not counted. A complete record of number of persons transported to the site by bus or limousine was obtained from the bus lines serving the area. No attempt was made to determine number of persons using private dwellings or lodge and motel units, either day or night.

The daily sampling schedule is summarized as follows:

1. The first 15 minutes of each sampling round (0900-0915; 1045-1100; 1230-1245; 1415-1430) were spent in making a persons-per-vehicle count.
2. In the next 1-1/2 hours of each sampling round (0915-1045; 1100-1230; 1245-1415; 1430-1600) the observer circulated through the base area to record activities, make a vehicle count, and hand out post card questionnaires at ski lifts.
3. From 1600 until 1630 each sample day the observer made a final vehicle count.

In addition to providing estimates of current recreation use, provision was also made for testing relationships between use and some related indicator with which use estimates might be revised in future years. Daily and season-long records were obtained from Brighton Winter-Sports Site concessionaires and the State of Utah Highway Commission:

1. Restaurant sales at Majestic Manor Lodge.
2. Equipment rental at the ski-equipment shop.
3. Ticket sales at the three ski lifts.
4. Traffic-count record of vehicles associated with the winter-sports site. A magnetic-loop, printout-type counter was installed at the entrance to Brighton.
5. Traffic-count record of vehicles entering Big Cottonwood Canyon on State Highway U-152. The counter, located approximately 14 miles from Brighton at the mouth of canyon, is a magnetic-loop, printout-type counter maintained by the highway department. In the winter the highway on which this counter is located is closed south of the turnoff to Brighton, so all traffic entering Big Cottonwood Canyon must exit by the same road.

The sampling technique incorporated thre separate procedures, as follows:

1. Estimating total undifferentiated us and number of visits,[1] without regard to kin of activity.
2. Estimating use by activity, includin skiing.
3. Determining average length of ski tim and other skier characteristics by questionnaire.

Total undifferentiated use, which include all activities, and number of visits were estimated by counting vehicles associated wit the site, observing how long vehicles staye and determining average number of person per vehicle.

A sampling model designed by James[2] wa used to estimate all activities, other than slop skiing, at the winter-sports site. During eac sampling round, the observer recorded (For 4.0, Appendix) the number of persons assoc ated with each activity listed below:

Spectator (sports and games)
Resort and commercial public service
Sledding and tobogganing
Snow play
Skiers (collateral activities)[3]
Viewing scenery
Recreation residence
Nonrecreation (workers)

Skiing was estimated independently by subtracting total hours of use of all other activities from total hours of undifferentiate use. This calculation procedure was necessary because much skiing occurred far removed from the base area where it could no be observed.

A one-question post card questionnaire wa administered to determine average number o hours of skiing per day per skier. The objective of the questionnaire phase of the stud was to determine the effectiveness of thi approach in estimating total skiing us The post card questionnaire was self-addressed, franked, and contained the questio "How many hours did you actually spend to

---

[1] In this report, a visit was considered as one perso visiting the ski area all or part of a day.

[2] James, George A. Instructions for using traff counters to estimate recreation visits and use on developed sites. U. S. Forest Serv. Southeast. Forest Ex Sta., 12 pp. illus. 1966.

[3] This category included persons in the base are who were carrying or wearing skis, but at time o observation were not on the slopes nor waiting in th ski-lift lines. Collateral ski activities included pu chasing lift tickets; renting, waxing, or repairing ski standing, walking, or resting on skis; etc.

Figure 2.—*Majestic Manor and two of the Brighton lifts—Majestic on the left and Mary on the right.*

day on the ski slopes, in the lift lines, and on the lifts? (Do not include time spent eating, purchasing lift tickets, in the parking lot, ski shop, etc.)" At each of the three ski lifts, during each sampling round, the observer spent exactly 5 minutes distributing post card questionnaires to skiers about to enter the lift (fig. 2). A brief explanation of study objectives was given by the observer, who then asked each skier whether he had received a post card that day. Post cards were given only to those who had not already received one. Skiers were requested to complete and mail the post card as soon as possible.

The observer recorded the following information on each post card before handing it out:

Date
Hour
Lift number
Age class of skier, by code[4]

In addition, the following information was collected during each 5-minute period at each lift, to determine rate of questionnaire response and to determine number of skiers on hourly and daily bases:

1. Total number of cards handed out.
2. Total number of skiers passing observer.
3. Number of persons who had already received cards, number of children too young to be given cards, number of persons refusing cards, number of workers, and number of persons who should have been given cards but were not because of the need to keep the line moving and lift chairs full.

Analysis and Results

Calculations for estimating total ***undifferentiated*** recreation use were based on the assumption that vehicles observed during each sampling round remained for the duration of that sampling round. For example, vehicles observed during the 0900-1045 round were assumed to have remained for 1-3/4 hours. Total vehicle-hours were calculated for each sample day.

A season-long, persons-per-vehicle average was determined from the 15-minute counts made at the site entrance. Average number of persons per vehicle was 1.98 on weekdays, based on 322 persons in 163 vehicles. Average number of persons per vehicle on weekends/holidays was 2.77, based on 1,928 persons in 696 vehicles. The season-long average was 2.62 persons per vehicle. Total undifferentiated use on each sample day was obtained by multiplying vehicle-hours by average number of persons per vehicle.

Two separate regression analyses (simple linear) were run to produce estimates of total undifferentiated use based on two independent indicator variables. The independent variables used were traffic counts (vehicles) from the Big Cottonwood Canyon counter,[5] and ski-equipment rentals (dollars).

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[4] The observer determined age without asking. Codes used were: Group 1—child, 8-12 years old; Group 2—adolescent, 13-18; Group 3—adult, older than 18. Cards were not given to children younger than 8.

Relationships between use and the independent variables were strong, and resulted in use estimates of good precision. The use-traffic count relationship was the more precise. The formula shown below is recommended for future updating purposes.

Y (undifferentiated use) = $a(N)+b(X_S)$, where "a" and "b" are constants, "N" is number of days in recreation season, and X_S is season-long vehicle count from Big Cottonwood Canyon counter.

$Y = -93.6832(129)+0.1829(226{,}553$ vehicles)

= **29,352 visitor-days of undifferentiated recreation use for 129-day season.**[6]

The confidence interval calculated at the 95-percent level of probability is ± 10.3 percent of the estimated value of Y.

Procedures for estimating number of visits to Brighton were similar to those used for determining total undifferentiated use. The largest number of vehicles on the site at any one time on each sample day was multiplied by mean-number-of-persons-per-vehicle to determine total visits for that day.[7] Number of visits on each sample day was regressed on traffic count from the Big Cottonwood Canyon counter to determine season-long number of visits. Estimate, confidence interval, and regression formula are shown below:

$Y(\text{visits}) = -189.7104(129)+0.4213(226{,}553)$
$= 70{,}974$[6]

The confidence interval calculated at the 95-percent level of probability is ± 9.8 percent of the estimated value of Y.

Peak use occurred from 12:30 to 4 p.m. on 14 of the 18 randomly selected sample days, and between 10:45 a.m. and 12:30 p.m. on 4 sample days. On no occasion did peak use occur from 9 to 10:45 a.m.

The next step was to generate an estimate of use for ***each*** activity (Form 4.0, Appendix). Numbers of persons engaged in each activity (except skiing) were regressed on 24-hour traffic count from the Big Cottonwood Canyon counter (X1) and on 24-hour restaurant sales (X2) to produce two separate use estimates and to determine which variable was the best indicator of use. Vehicle count and restaurant sales were both strongly related to use by activity.[8] Estimates, confidence interval, and regression formulas are shown in tables 1 and 2.

Because much skiing occurred in locations where it could not be directly observed for sampling, a "subtraction" type of analytical approach was necessary for estimation purposes. For this calculation, skiing was assumed to be the use remaining after total use in all other activities was subtracted from total undifferentiated use. Visitor-days of skiing use were calculated for each sample day, and an estimate of season-long skiing use generated by regression analysis. The indicator variable used was vehicular traffic at Big Cottonwood Canyon. Estimate, confidence interval, and regression formula are:

$Y(\text{skiing use}) = -56.1352(129)$
$+0.1144(226{,}553)$
= 18,677 visitor-days of skiing use[9]

Confidence interval is ± 13.9 percent at the 95-percent level of probability.

The last remaining step for calculating total season-long use was to determine the amount of use by persons transported to Brighton by bus and limousine. Companies serving the area furnished a complete record of dates and times of service, and the number of passengers on each trip. It was possible, therefore, to determine accurately the volume of use resulting from commercial transportation facilities.

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[5] The traffic counter installed at the entrance to Brighton did not yield a usable record because much of the traffic-count data were not transmitted from the detector to the tape. This was not discovered until after the study was completed. The traffic counter was checked every third day during the 129-day season. But, because the counter was running and appeared to be functioning satisfactorily during each examination, it was assumed the instrument was working properly.

[6] Does not include use by persons transported to Brighton by bus or limousine. These visitors will be discussed later.

[7] Because of the considerable driving distance involved, persons visiting the Brighton Winter-Sports Site remain for all or part of a day. They do not "come and go" with frequent regularity, as is the case on most developed recreation sites.

[8] It is recommended that the traffic-count record be used for the next several-year period for updating purposes because this record will be available every year at no extra effort and cost. Restaurant sale data and other concessionaire records could also be used for updating purposes, but the added cost and extra effort required of the concessionaires to furnish this information make its use undesirable.

[9] Does not include skiing use by persons transported to Brighton by bus or limousine, or collateral skiing activities within the base area.

Figures furnished by local bus and limousine companies revealed that 6,685 persons were transported to Brighton during the sample study period, and accounted for 2,020 visitor-days of undifferentiated use. Adding these 2,020 visitor-days to the 29,352 visitor-days of undifferentiated use produced a season-long estimate of 31,372 visitor-days of undifferentiated use.

To 70,974 visits was added 6,685 persons, resulting in a season-long visit estimate of 77,659. Of the 6,685 persons transported by bus and limousine, 6,348 came to attend ski classes which were conducted on 18 days during the season. Buses arrived at 10 a.m. and departed at 1:30 p.m.; classes were conducted 2 hours, from 10 a.m. to noon. Assuming that most persons who attended the classes skied for the entire 3-1/2-hour period, an estimate of 1,852 visitor-days of skiing use resulted from bus transportation. To 18,677 visitor-days of skiing use, 1,852 visitor-days were added to obtain a season-long estimate of 20,529 visitor-days of skiing use.

Table 1.—*Estimates of recreation use, except skiing, at the Brighton Winter-Sports Site, Utah, based on relationships (regression) between use and vehicular traffic count at Big Cottonwood Canyon, November 23, 1966 through March 31, 1967*

Activity	Use estimate	Confidence interval[1]	Regression formula
	Visitor-days[2]	*Percent*	$Y = a(N) + b(X_S)$[3]
Spectator	615	±21.2	$Y = -1.5554\,(N) + 0.0036\,(X_S)$
Resort/commercial	5,363	±14.3	$Y = -21.2999\,(N) + 0.0358\,(X_S)$
Sledding & tobogganing	87	±13.9	$Y = -0.5583\,(N) + 0.0007\,(X_S)$
Snow play	230	±14.0	$Y = -0.8545\,(N) + 0.0015\,(X_S)$
Skiers (collateral activities)	3,279	±12.6	$Y = -13.7417\,(N) + 0.0223\,(X_S)$
Viewing scenery	61	±34.3	$Y = -0.2353\,(N) + 0.0004\,(X_S)$
Recreation residence	84	±23.0	$Y = -0.4004\,(N) + 0.0006\,(X_S)$
Nonrecreation (workers)	1,071	± 6.1	$Y = 2.1889\,(N) + 0.0035\,(X_S)$
Total use, all	10,816	± 9.8	$Y = -36.4567\,(N) + 0.0685\,(X_S)$

[1] Confidence interval at the 67-percent level of probability, expressed as percent of the estimate. Example: If estimated season-long resort/commercial use is 5,000 visitor-days for a given sample, and the confidence interval is ± 10 percent at the 67-percent level of probability, we construct the interval 4,500 to 5,500 visitor-days. On the average, 67 percent of such intervals will include the true value if we sample an unlimited number of times.

[2] Recreation use which aggregates 12 person-hours. May entail 1 person for 12 hours, 12 persons for 1 hour, or any equivalent combination of individuals or group use, either continuous or intermittent.

[3] Use of the regression formula is shown in the Appendix.

Table 2.—*Estimates of recreation use, except skiing, at the Brighton Winter-Sports Site, Utah, based on relationships (regression) between use and restaurant sales at Majestic Manor Restaurant, November 23, 1966 through March 31, 1967*

Activity	Use estimate	Confidence interval[1]	Regression formula
	Visitor-days	*Percent*	$Y = a(N) + b(X_S)$
Spectator	595	±23.5	$Y = 1.0405\,(N) + 0.0114\,(X_S)$
Resort/commercial	5,082	±13.7	$Y = -2.9100\,(N) + 0.1349\,(X_S)$
Sledding & tobogganing	74	±19.5	$Y = -0.1129\,(N) + 0.0022\,(X_S)$
Snow play	228	±16.8	$Y = 0.2362\,(N) + 0.0049\,(X_S)$
Skiers (collateral activities)	3,133	±13.7	$Y = -0.5800\,(N) + 0.0793\,(X_S)$
Viewing scenery	105	±21.3	$Y = 0.1260\,(N) + 0.0011\,(X_S)$
Recreation residence	90	±24.4	$Y = 0.1025\,(N) + 0.0019\,(X_S)$
Nonrecreation (workers)	1,058	± 6.7	$Y = 4.5044\,(N) + 0.0118\,(X_S)$
Total use, all	10,318	±10.1	$Y = 2.4069\,(N) + 0.2474\,(X_S)$

[1] Confidence interval at the 67-percent level of probability, expressed as percent of the estimate.

A summary of estimated use which occurred at Brighton follows:[10]

Total use ....31,372 visitor-days
(undifferentiated by activity)

Total number of visits....77,659

Skiing use (on slopes)....20,529 visitor-days

All other use......................10,816 visitor-days
(excludes skiing[11])

Twenty-two percent of total undifferentiated use occurred on weekdays and 78 percent occurred on weekends/holidays. Average length of stay per person per day at Brighton was 4.8 hours (based on 77,659 visits and 376,464 hours of undifferentiated use).

The sampling techniques used at Brighton were specifically designed to yield two ***independent*** estimates of skiing use and to determine which of the two techniques worked better. One technique for estimating amount of skiing use has been discussed. The other approach was to calculate an estimate of skiing use from the total number of different skiers on each sample day (based on information obtained during each 5-minute period at each ski lift) and average number of hours that each person skied (from completed post card questionnaires).

We failed in this endeavor. One vital piece of information was omitted in the sampling design; this oversight made it impossible to generate an estimate of skiing use based on the questionnaire. An additional question needed to be asked at the time post card questionnaires were handed out: "Up to the present moment, how many times have you used ***any*** of the lifts today?" Without this information it was not possible to determine the total number of ***different*** persons using ski lifts on each sample day.[12]

Post card questionnaires and data collected during the 5-minute periods at each lift were valuable nevertheless, and provided useful information about the skiing population:

1. Based on the return of 469 completed post card questionnaires, the average length of skiing time per person was 3.85 hours on weekdays and 4.35 hours on weekend days and holidays. The average for all days was 4.24 hours.
2. Skiers between the ages of 13 and 18 spent more time on the slopes, on the average, than younger and older skiers, as follows:

Age	Average number of hours skied	Questionnaires returned
Years	*Hours*	*Number*
8-12 (child)	3.87	62
13-18 (adolescent)	4.68	189
Over 18 (adult)	3.99	218

3. Approximately 3 percent of the sampled population using the ski lifts were less than 8 years old.
4. Only 1 percent of the sampled population refused to accept a post card questionnaire. Of the 2,231 persons who received a post card, 469 completed and returned them —a response rate of only 21 percent.

Discussion

The pilot sampling study, though not successful in all respects, provided valid estimates of current use, and formulas to update use estimates for the next several-year period. Estimates and formulas are based on the traffic record from Big Cottonwood Canyon. Valuable knowledge gained will be useful in designing future sampling studies.

Total cost of this sampling study was $1,865, not including the traffic counter ($700) installed at the entrance to Brighton. Assuming that relationships between use and traffic pattern at Big Cottonwood Canyon remain constant for several years, and estimates can be updated annually for another 4 years, average annual cost becomes approximately $373.

This total cost is low and can be further reduced in future sampling on other winter-sports sites by reducing the number of sampling days. For example: A separate analysis of the Brighton data disclosed that acceptable estimates of use could have been obtained using 12 sample days instead of 18. With sampling costs running about $30 per day, an additional savings of $180 can be made.

It is unfortunate that the questionnaire phase of the Brighton study was not successful—it would have provided an excellent crosscheck of skiing use at little extra cost. Acceptable estimates of use were obtained without questionnaire, however, and future sampling efforts need not include this phase. But, because questionnaires can provide information of considerable value at little additional cost, their use should be fully considered.

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[10] All estimates include daytime use which occurred between 9 a.m. and 4:30 p.m. during the period November 23, 1966 to March 31, 1967. To these estimates must be added use which occurred before and after the sampling period dates and late evening and overnight use, in order to estimate **total use** of the area.

[11] Includes an estimate of 1,071 visitor-days of nonrecreation use by workers, and 3,279 visitor-days of collateral skiing activity which occurred within the base area.

[12] Information obtained during the 5-minute periods at each lift made it possible to estimate **total** number of rides on all lifts on each sample day. But, because most persons used the lifts several times each day, it was not possible to determine total number of **different** persons using the lifts. Total number of rides on each lift would be useful in estimating total amount of skiing, if mean round-trip skiing time per lift was also known.

Distributing questionnaires to skiers about to enter ski lifts, as was done in the Brighton study, is not recommended. The low response rate can likely be attributed to the fact that many post cards were lost or damaged before the skiers left the area. Most post cards were stuffed either into skiers' gloves or placed in their woolen caps because few ski outfits contain pockets. Neither does it appear practical to administer a questionnaire, however short, to departing skiers either at the parking-lot exit or on the highway because of the possible traffic jam it might create. A random selection of recreationists in parking lots loading their vehicles for the return home might be a more satisfactory location for administering a questionnaire. This and other possible locations should be considered in future sampling efforts.

In future sampling efforts on winter-sports sites, a magnetic-loop, printout-type traffic counter often will be installed and used for estimate-updating purposes. It is recommended that counter installation and maintenance be done by a trained manufacturer's representative. To be of maximum usefulness, an accurate, unbroken, season-long traffic-count record must be obtained.

Where possible, other information, such as restaurant sales, equipment rentals, and water consumption, should always be collected to determine which variable is the best indicator of use. Data obtained from concessionaires were not needed in the Brighton study because of strong relationships between use and vehicular count at the Big Cottonwood Canyon counter site. Had this not been the case, however, the concessionaire data would have been invaluable for updating use estimates in future years.

The sampling method used at Brighton, excluding the post card-questionnaire phase, can be recommended for use at comparable winter-sports sites, and where favorable cost/benefit values will result. The techniques for obtaining use estimates are considered sound and, with necessary modification to fit each site, can yield acceptable estimates of use at low cost.

APPENDIX

Regression Formula for Calculating and Updating Use Estimates

For several years, the only information needed to update use estimates is an accurate record obtained from the traffic counter located at Big Cottonwood Canyon for the same period as studied.

To calculate the amount of resort/commercial use during the 1967-68 (or 1968-69 or 1969-70, etc.) season, solve formula using current season-long vehicle-count value for the 129-day period.

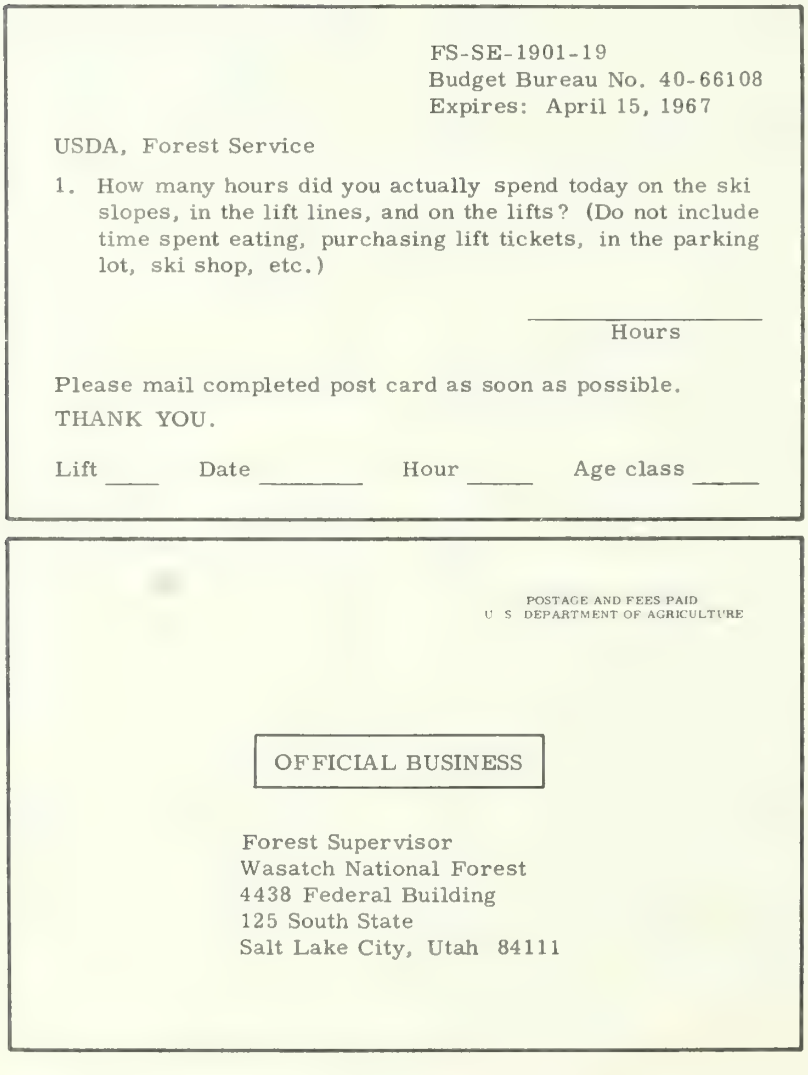
Example:

The formula and calculations for obtaining an estimate of resort/commercial use is:

$Y(\text{resort/commercial use}) = a(N)+b(X_s)$, where "a" and "b" are constants, N=number of days in the sampling season, and X_s=season-long vehicle count from Big Cottonwood Canyon counter.

$$= -21.2999(129)+0.0358(226{,}553)$$
$$= -2{,}747.7+8{,}110.6$$
$$= 5{,}363 \text{ visitor-days}$$

Example of post card questionnaire used to obtain an estimate of average number of hours skied by each respondent on sample day (reduced in size by about one-fourth):



FS-SE-1901-19
Budget Bureau No. 40-66108
Expires: April 15, 1967

USDA, Forest Service

1. How many hours did you actually spend today on the ski slopes, in the lift lines, and on the lifts? (Do not include time spent eating, purchasing lift tickets, in the parking lot, ski shop, etc.)

____
Hours

Please mail completed post card as soon as possible.

THANK YOU.

Lift ____ Date ________ Hour _____ Age class _____

POSTAGE AND FEES PAID
U S DEPARTMENT OF AGRICULTURE

OFFICIAL BUSINESS

Forest Supervisor
Wasatch National Forest
4438 Federal Building
125 South State
Salt Lake City, Utah 84111

S.E.F.E.S.
FORM 4.0

DAILY AND SEASONAL SUMMARY OF INDICATOR VARIABLES AND USE

Card No. 1	IDENTITY	Card (1-2)	Region (3-4)	Forest Name No. (5-6)	District Name No. (7-8)
		Principal Site No. (9-12)	Kind (13-15)	Date of Sample (16-21) — —/— —/— —	
		Sampling Technique Used (22-23)	Total Days in Recreation Season (24-26)		

Card No. 2	INDICATORS	Restaurant Sales ($)	Lift Tickets Sold (No.)	Equipment Rental ($)	Vehicle Count (Axles)	Other (Specify)	Other (Specify)
					0900 (Sample Day)		
					0900 (Next Day)		
		(22-26)	(27-31)	(32-36)	Diff. (37-41)	(42-46)	(47-51)

Card No.		Time	1.3 Spectator (Sports & Games)	46.1 Resort & Comm. Public Serv.	51.2 Sledding & Tobogganing	51.4 Snow Play	51.3 Skiing (Collateral Activities)	1.1 Viewing Scenery	46.3 Recreation Residence	Non-recreation (Workers)
	PERSONS		(22-26)	(27-31)	(32-36)	(37-41)	(42-46)	(47-51)	(52-56)	(57-61)
3		0915-1045								
4		1100-1230								
5		1245-1415								
6		1430-1600								

Observer : ____________________

Date : ____________________

U.S.D.A. Forest Service Research Paper SE-43 December 1968

THE GASTON FIRE

APR 29 1969

U.S. Department of Agriculture - Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

THE GASTON FIRE

by

John H. DeCoste, Dale D. Wade, and John E. Deeming[1]

INTRODUCTION

South Carolina experienced one of its worst forest fire seasons during the spring of 1966. Following a 3-week period in March when little or no rain fell and the fire incidence over the entire state peaked at more than 175 per day, the Governor issued a proclamation on the afternoon of March 31, closing the woods and forest lands of South Carolina to burning. On April 1 and 2, the Gaston Fire--an intense, fast-moving, wind-driven conflagration--burned over 7,400 acres of sandhills country in the central part of the state. Initially, there were two separate wildfires in the same vicinity, the Gaston and the Edmund; but they eventually burned together.

This is the story of the Gaston Fire as documented by a fire research team from the Southern Forest Fire Laboratory. It is hoped that this publication will be of value in providing data to substantiate laboratory findings on fire behavior and in aiding in the development of fire behavior hypotheses. Such a case history will also add valuable knowledge useful for fire control. Fire control personnel may, under similar conditions, be better able to predict fire behavior and thereby increase the effectiveness of their control actions.

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[1] The authors are Associate Fire Behavior Scientist, Associate Fire Behavior Scientist, and Associate Fire Control Scientist, respectively, at the Southern Forest Fire Laboratory, Macon, Georgia.

Acknowledgments. --We would like to express our sincere appreciation to the South Carolina State Commission of Forestry, whose wholehearted cooperation and assistance made this report possible. In particular, we would like to thank John Tiller, State Forester; John Shirer, Assistant State Forester for Forest Protection; and his assistants, Hugh Westbury, William Lindsay, and J. T. Hance.

In addition, we are very much in the debt of Jerry Kanupp, Fire-Weather Forecaster, U. S. Weather Bureau, for his assistance in the collection and interpretation of the weather information contained in this report.

We would also like to thank the other members of the documentation team from the Southern Forest Fire Laboratory--Edward Ach, James Coffin, and Sidney Harper. Mr. Ach made an additional contribution to this study through his work in preparing many of the charts and figures included herein.

The Gaston Fire was similar in meteorological aspects to the famous Buckhead Fire of 1956 in north Florida which developed in the warm sector of a low-pressure system and was later affected by a dry, cold front. A warm-sector fire occurs in the warm air within the circulation of a cyclone ahead of the cold front. A cold front fire occurs within the cold air behind the cold front.

On Friday, April 1, 203 fires throughout the state burned a total of 30,000 acres. On Saturday, 169 fires were reported with a loss of more than 25,000 acres. For the week ending Saturday, April 2, a total of 78,867 acres were burned (fig. 1).

The Gaston Fire burned in Forestry District 5, the hardest hit district. On April 1, 24 fires were reported in this district with a loss of 9,636 acres; on April 2, 36 fires were reported that burned 8,932 acres. On both days the burned acreage in District 5 totaled almost one-third of that for the entire state.

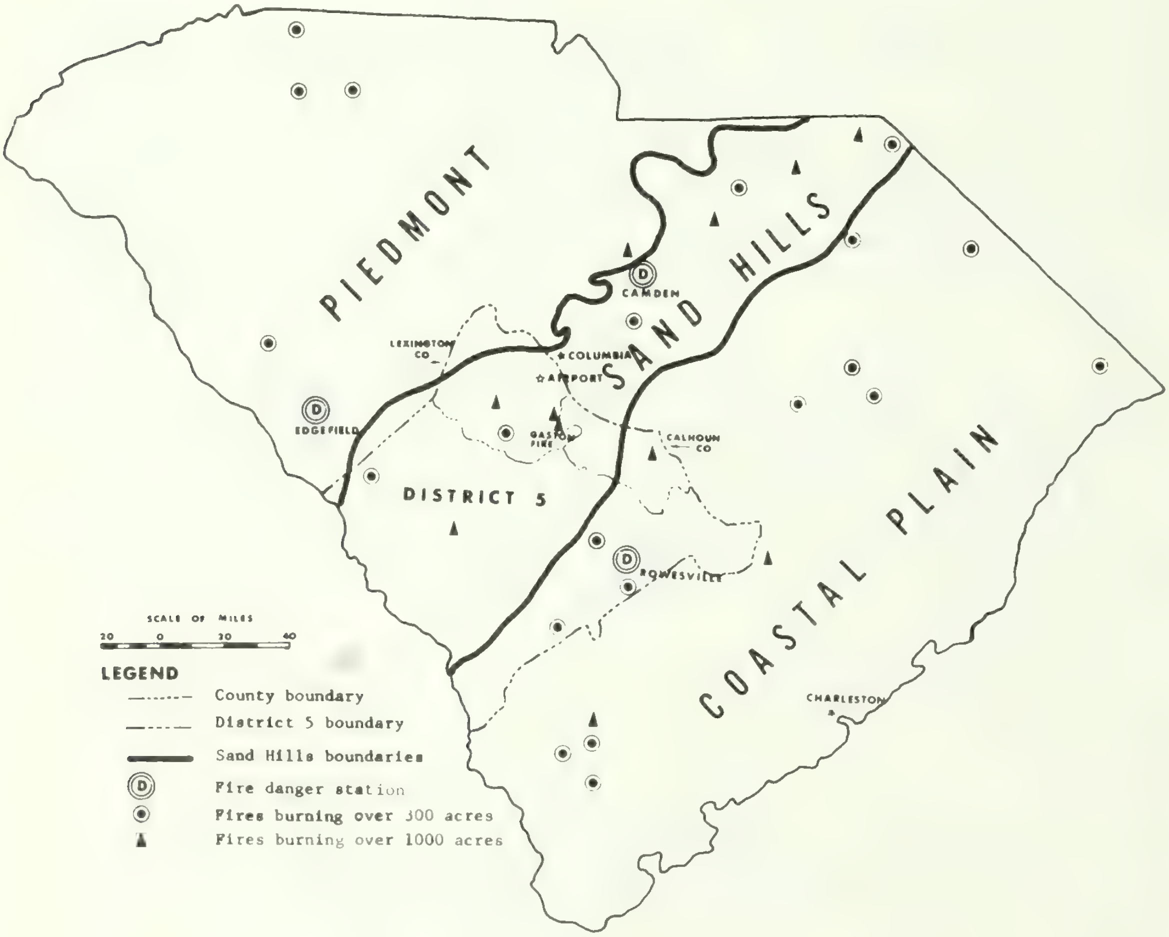

Figure 1.--Location of the major fires which occurred during the period from March 30 through April 3 in South Carolina.

The numerous large fires extended the fire control organization beyond its capabilities. Human endurance was pushed to the breaking point. Heretofore, tractor-plows were the mainstay of the fire suppression organization. During this severe period, however, such equipment was virtually ineffective for direct attack on many of the fires. The Gaston Fire was such a fire.

Fuels were highly flammable and weather conditions extreme. The airmass was unusually dry; and winds, both on the ground and aloft, were favorable for rapid fire spread. Convective activity was limited and, except for the major run late Friday, did not appear to play a major role in the fire's behavior. Convection columns generally were limited in height and short-lived because of the unusually rapid increase of windspeeds with height above the ground.

The fire made several major runs, presented difficult control problems, burned an extensive area and, at times, exhibited unusual fire behavior. Although the fire reached blowup proportions only during its run Friday evening, it was certainly above the average intensity of the majority of wildfires.[2]

SITUATION

Weather was the dominant factor governing the behavior of the Gaston Fire. Topography and manmade features, such as roads, ponds, railroad rights-of-way, and a golf course, changed the fire behavior pattern on several occasions.

Weather[3]

The weather during the month preceding the Gaston Fire was the driest on record for a March since 1955. Rainfall in the central sections of South Carolina averaged less than two-thirds of the normal for March, and most of that fell 4 weeks prior to the fire. The U. S. Weather Bureau Station at the Columbia Municipal Airport, 8 miles north of Gaston, recorded 2.09 inches on March 3 and 4, 0.12 inch on the 15th, and 0.02 inch on the 24th.

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[2] High-intensity or blowup fires can reach intensities of 20,000 to 30,000 B.t.u. per second per foot of fire front in contrast to the majority of wildfires which reach less than 1,000 B.t.u. per second per foot of fire front. The high-intensity fire has a third, or vertical, dimension which may at times exceed the surface dimensions of the burning area.

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[3] For a comprehensive dissertation of the weather relative to the Gaston Fire, see Appendix.

During the week preceding the fire, the 8-100-0 Fire Danger Rating System indicated that the fire danger was in the extreme category with buildup indexes in the 90's and burning indexes in the 80's and 90's. On April 1 and 2, fire danger stations in the sandhills area reported buildup indexes of 100 and burning indexes of 100, both at the maximum.

Data for the 1st and 2nd of April from the three closest fire danger stations which use the National Fire Danger Rating System and the Columbia Municipal Airport are summarized (table 1). (See fig. 1 for location of the stations.)

Fuel

Fuel types within the burn were quite variable from the standpoint of density, quantity, composition, continuity, and arrangement. However, fuels may be categorized into several broad types:

1. *Young slash pine plantations (2 to 6 years old).*--The flash-fuel component was composed of cured broomsedge (*Andropogon virginicus* L.), grasses, and other herbaceous plants and weighed approximately 2.5 tons per acre. A typical slash pine (*Pinus elliottii* Engelm.) stand averaged 5 years in age and ranged from 4 to 7 feet in height.

Table 1.--Fire danger rating data - National System

APRIL 1, 1966

Station	Fine fuel moisture	Buildup index	Adjusted fuel moisture	Wind-speed	Spread index		Class day
					Timbered	Open	
	Percent		Percent	M.p.h.			
Camden	4.5	68	8	17	56	71	5*
Edgefield	4.5	72	7	18	60	71	5
Rowesville	3.5	73	6	28	85	100	5
Columbia Airport**	4.0	71	6	17	64	73	5
APRIL 2, 1966							
Camden	5.5	71	8	11	43	51	5
Edgefield	5.5	75	8	15	49	58	5
Rowesville	4.0	77	6	28	85	97	5
Columbia Airport**	5.0	74	7	21	69	79	5

*Extreme fire danger.
**Not an official fire danger station.

2. Immature slash pine plantations (7 to 18 years old).--These plantations, although generally void of brush and herbaceous plants, contained considerable amounts of cured broomsedge and grasses in the younger aged stands and heavy needle drape and an accumulation of litter in the older stands. Fine fuel averaged 3 tons per acre.

3. Natural longleaf pine stands (Cover type 70)[4].--These stands were variable in both age and size. The amount of brush also varied, but the older stands had a deep litter layer and much needle drape. Fine cured fuels weighed approximately 3.5 tons per acre in immature stands and 11.0 tons per acre in mature stands. A sampled stand of mature longleaf pine (Pinus palustris Mill.) ranged from 8 to 14 inches in diameter, 65 to 70 feet in height, and averaged 55 years in age.

4. Longleaf pine-scrub oak (Cover type 71).--Dense scrub oak (Quercus spp.) up to 3 inches in diameter predominated. There was considerable variation in density, age, and size of the longleaf pines. Flash fuels were composed primarily of broomsedge and hardwood leaf litter and weighed approximately 4 tons per acre.

5. Scrub oak (Cover type 72).--This type was composed predominantly of dense scrub oak up to 3 inches in diameter and 5 to 15 feet in height with some scattered large hardwoods up to 5 inches in diameter and an occasional longleaf pine. Leaf litter and some grasses were the principal flash fuels. Their continuity was variable but tended to be spotty. Fine fuel weights averaged approximately 4 tons per acre.

Moisture content samples of cured fuels were taken at several locations immediately prior to the passing of the fire's head (table 2). The moisture contents of most samples ran well below 10 percent.

Available fuel approached 100 percent of total fuel. Lower layers of litter were dry; moisture contents were generally only a few percentage points above that recorded for upper litter samples. Fuel moisture contents increased only slightly during the evening of April 1 because relative humidities remained low after the passage of a dry, cold front shortly after 1800 EST.

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[4] Society of American Foresters. Forest cover types of North America (exclusive of Mexico). 67 pp. 1962.

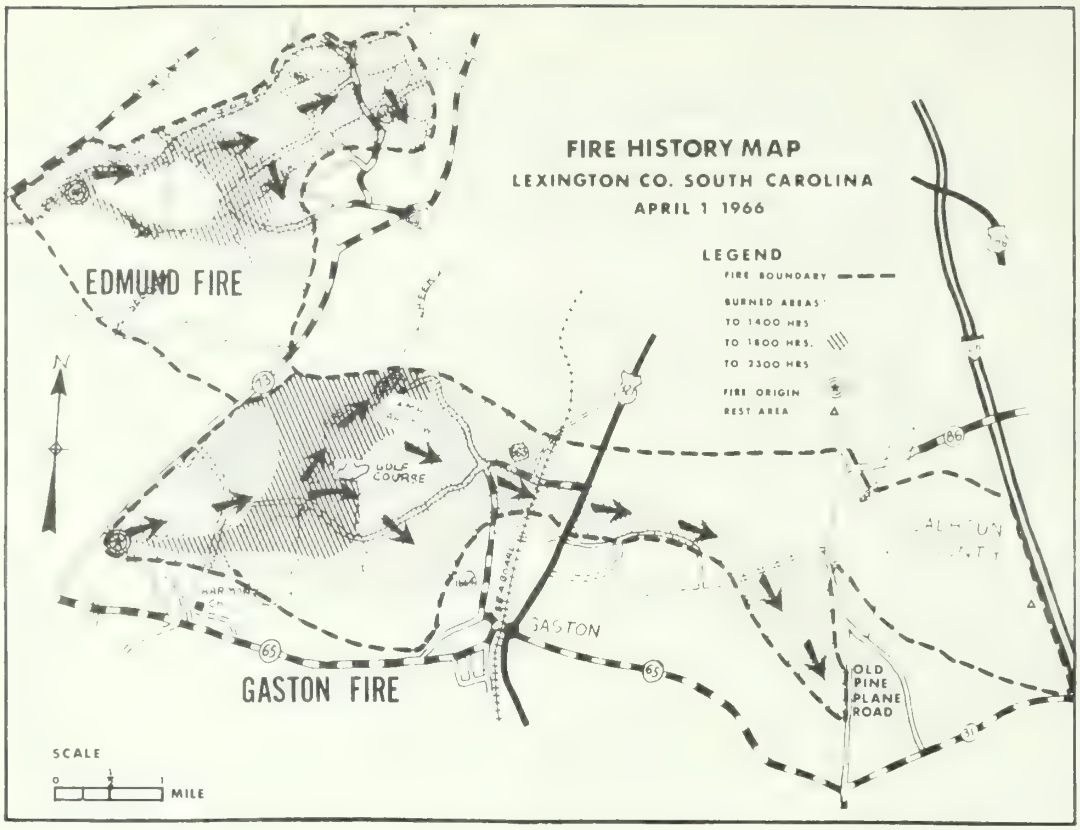

Figure 3.--Fire spread of the Gaston and Edmund Fires on April 1, 1966.

FIRE BEHAVIOR IN RELATION TO METEOROLOGICAL CONDITIONS

Friday, April 1, 1966

By 1000 EST, the wind at the Columbia Airport was gusting above 25 m.p.h. from the southwest, the temperature was 74° F., and the relative humidity was down to 26 percent (fig. 4).

The temperature continued to climb until it reached a maximum of 86° F. at 1400 EST. A winds aloft observation was made by visually tracking a small weather balloon (pibal: short for pilot balloon) just west of Columbia at 1410 EST. This sounding indicated that a favorable wind profile[5] existed but that fires might produce short-range spotting and spread at a rate of 1 m.p.h. The wind changed little until approximately 1600 EST when the gusts at the airport picked up to 46 m.p.h.

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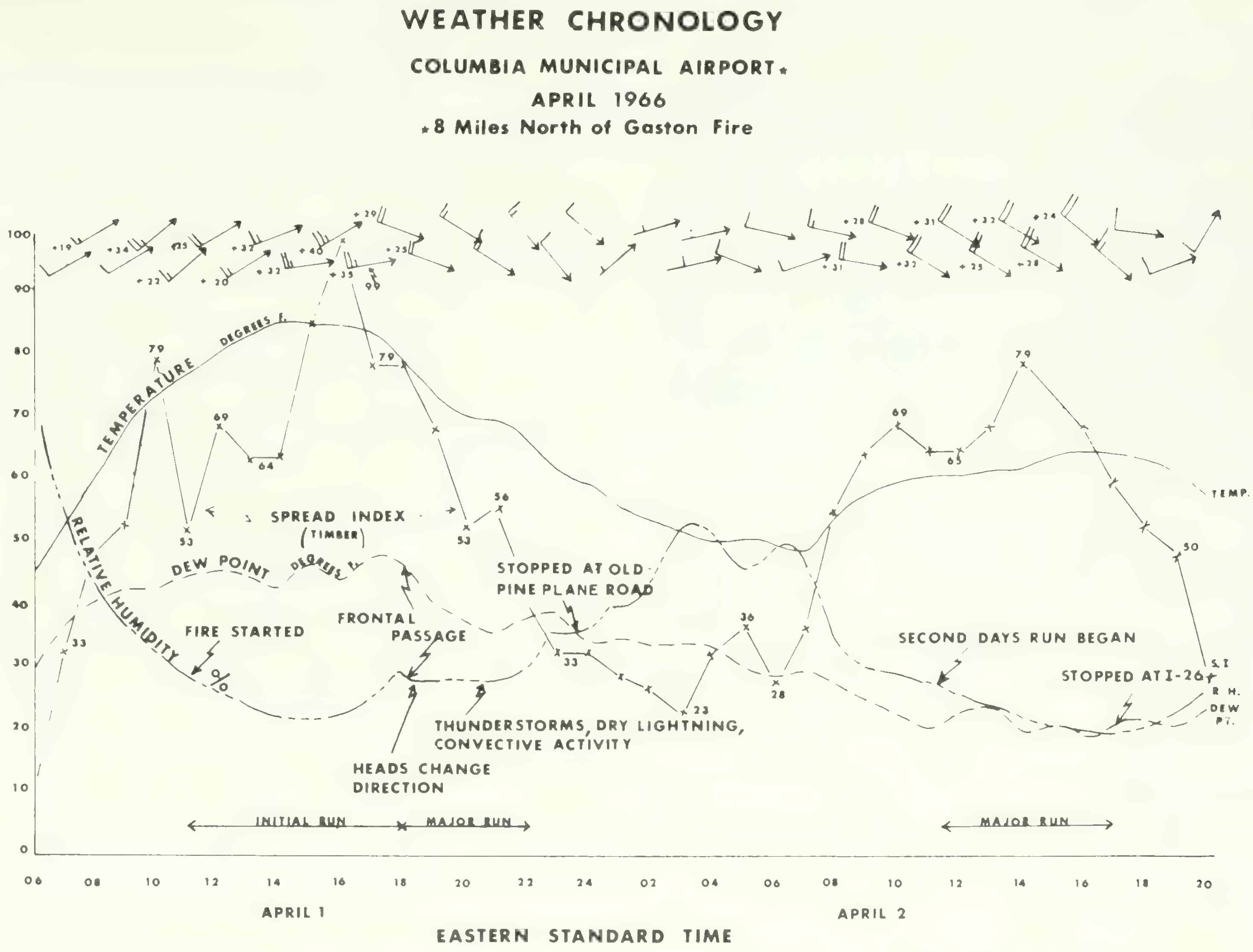
[5] A favorable profile is one which is not conducive to the buildup of a large convection column over a wildfire. However, certain favorable profiles can produce fires with high rates of spread and long-distance spotting. The classification of wind profiles presented in this paper is in accordance with the scheme presented by George M. Byram in: Atmospheric conditions related to blowup fires. U. S. Forest Serv. Southeast. Forest Exp. Sta. Pap. 35, 34 pp., illus., 1954.



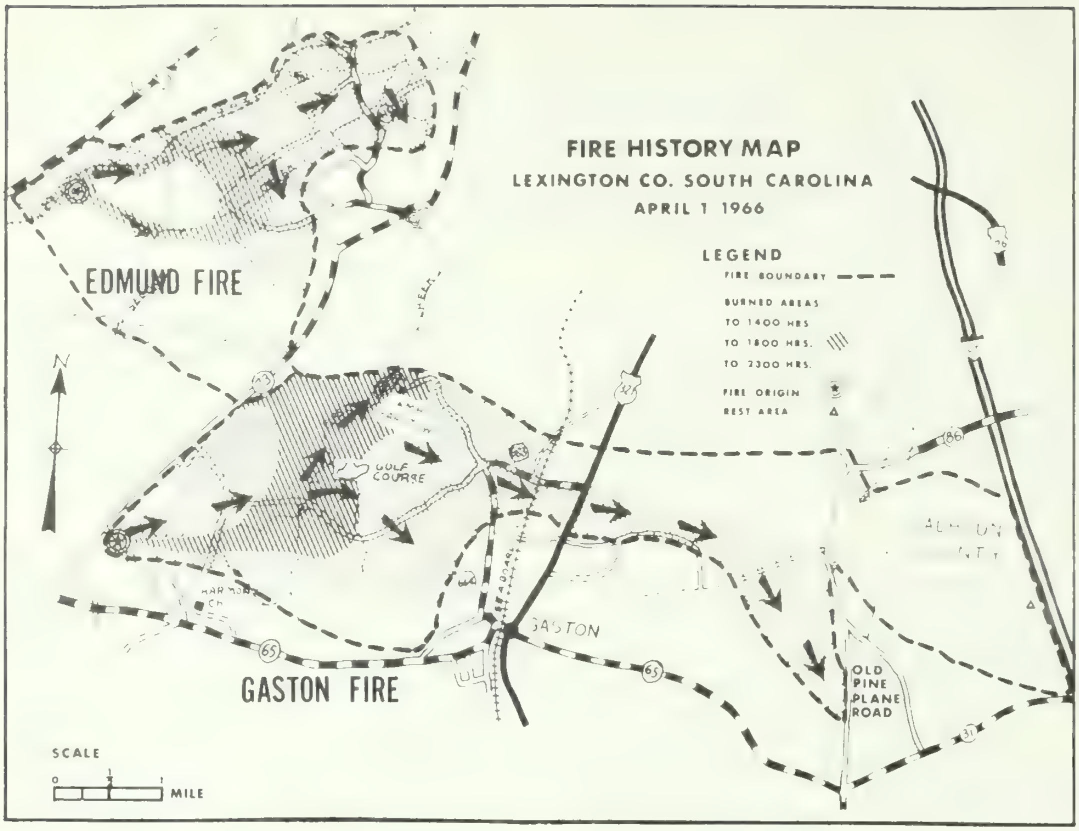
WEATHER CHRONOLOGY

COLUMBIA MUNICIPAL AIRPORT*

APRIL 1966

*8 Miles North of Gaston Fire

Figure 4.--Fire weather and the spread index during the Gaston Fire relative to time and fire behavior.



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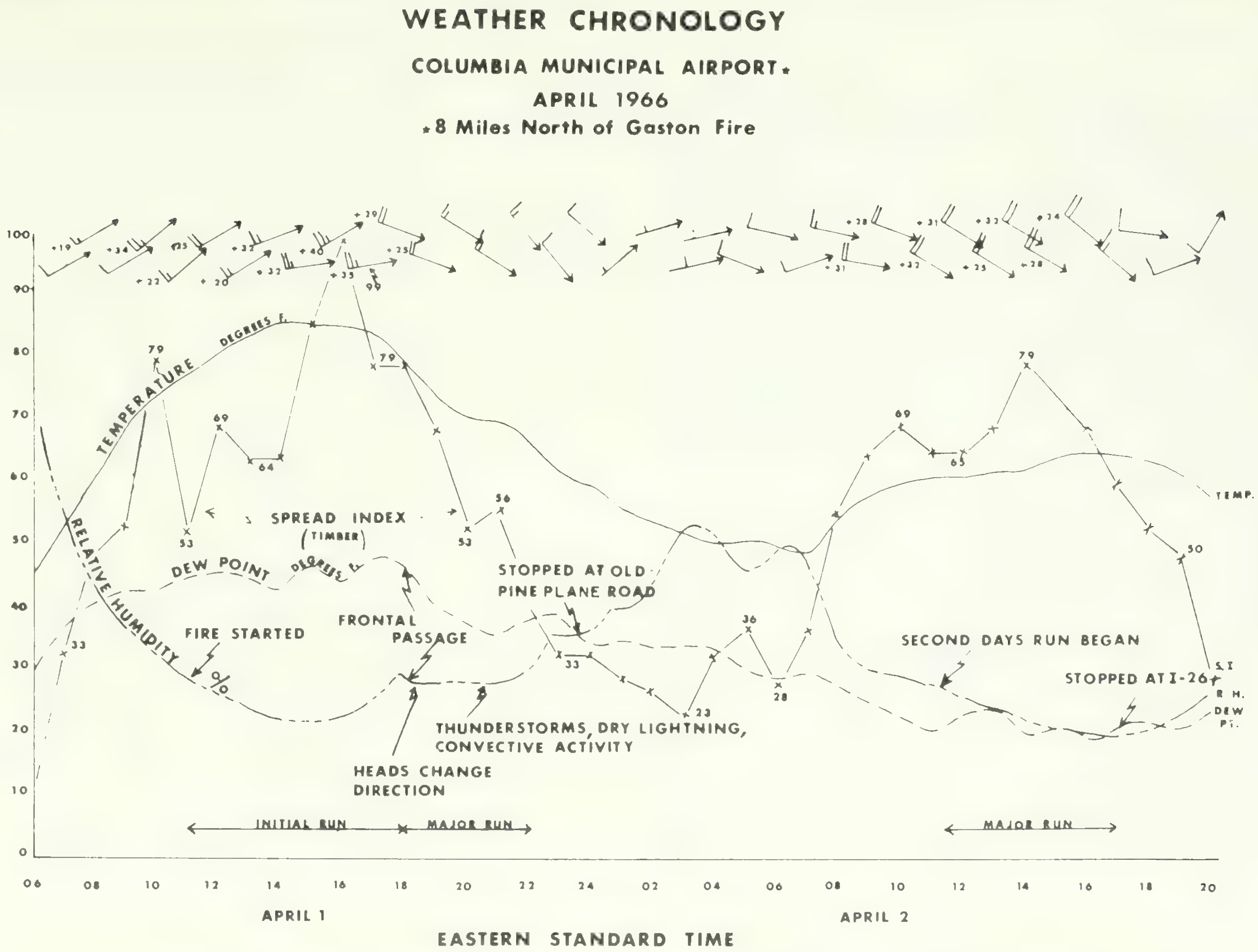
WEATHER CHRONOLOGY

COLUMBIA MUNICIPAL AIRPORT*

APRIL 1966

*8 Miles North of Gaston Fire

Figure 4. --Fire weather and the spread index during the Gaston Fire relative to time and fire behavior.

At 1345 EST, when an aerial observer arrived over the area, the Gaston and Edmund Fires were approximately 4 miles apart. At this time, the Gaston Fire was estimated at over 600 acres in size. The head was estimated to be over one-half mile wide and had already made a run of nearly 2 miles (fig. 3). Both fires were spreading rapidly to the east-northeast.

The rates of spread during this period averaged 1.7 m.p.h. Fire intensities ranged from 3,500 to 4,000 B.t.u. per second per foot of fire front, well above the average maximum of 1,000 B.t.u. per second per foot of fire front that Byram[6] gives for the majority of wildfires. No accurate determination of spotting distance ahead of the fire could be made because of the dense smoke; however, when the width of barriers which the fire crossed is considered, one-half mile is not an excessive estimate. The smoke lay nearly flat for 3 to 4 miles in front of the fire and then billowed up to over 3,000 feet in altitude.

At approximately 1700 EST, the main head of the Gaston Fire was split by a golf course. By 1800 EST, the left head had moved into the Camp Barstow area 1 mile to the northeast of the golf course. Shortly after 1800 EST, a dry, cold front which had moved through the western sections of the state during the day passed through the Gaston area. The wind shifted from 240° to 290°; and the relative humidity, which had begun its normal diurnal rise, leveled off at 28 percent. The wind at the fire site was averaging 15 m.p.h. and gusting to 27 m.p.h.

A pibal run was made at 1740 EST just prior to the passage of the cold front over the fire. These data showed that the winds above the surface increased steadily to 49 m.p.h. at 1,700 feet and then decreased to 24 m.p.h. at 2,600 feet, where the run was terminated because of poor visibility due to smoke. The sounding indicated a favorable profile, but one which could still produce rates of fire spread up to 1 m.p.h. with short-distance multiple spotting (fig. 5).

Following the 50° clockwise wind shift, the Gaston Fire began one of its major runs. Both heads changed direction and began running at a high rate of spread to the east-southeast.

The left (north) head crossed the road 200 yards north of the intersection of County Routes 663 and 664 at 1825 EST (fig. 3). The rate of spread increased to 3 m.p.h., or nearly double its previous rate. Fire intensity also increased to between 6,000 and 11,000 B.t.u. per second per foot of fire front. The rate of spread did not seem to be affected by fuel type or manmade features. The fire crossed several dirt and paved roads and a railroad right-of-way. Wind-driven flames were observed lying horizontally 30 feet in front of the fire zone. By 1850 EST, the north head had made a run of approximately $2\frac{1}{4}$ miles to a point just east of U. S. Highway 321.

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[6] Byram, G. M. Forest fire behavior. In Forest Fire: Control and Use, K. P. Davis (ed.). Chapter 4, pp. 90-123. New York: McGraw-Hill Book Co., Inc. 1959.

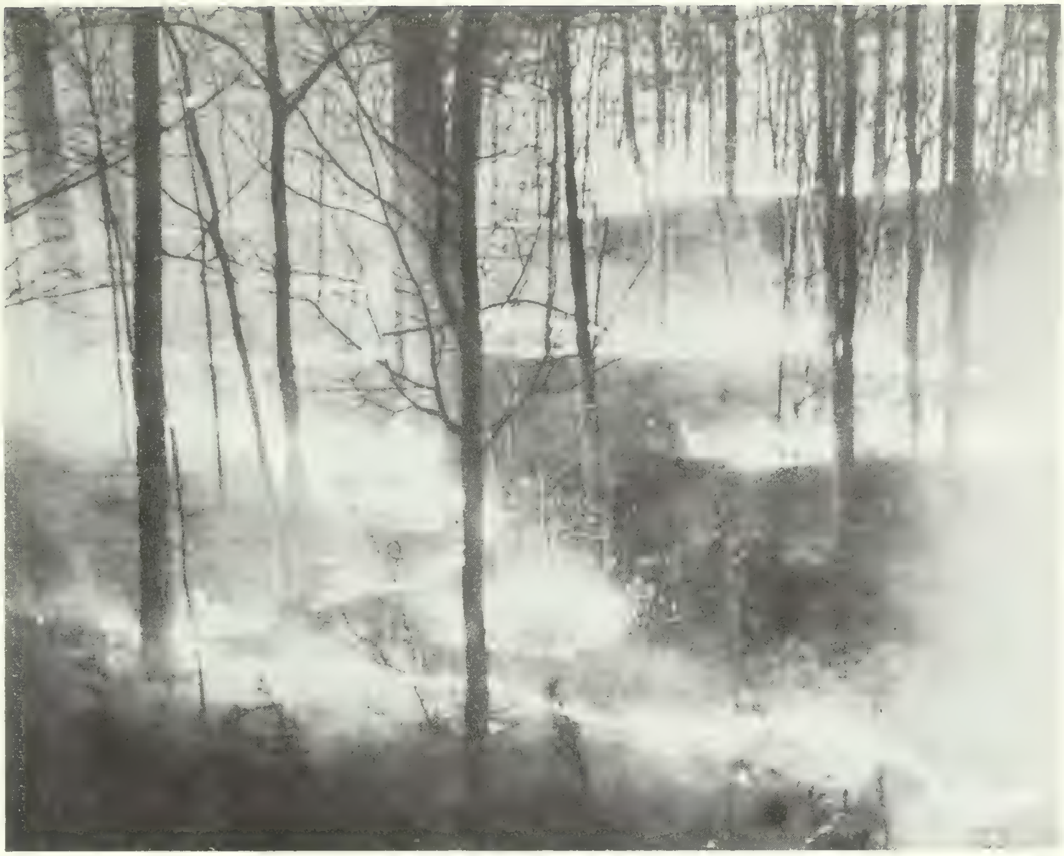

Figure 5.--Spotting during the evening of April 1 when the fire crossed U. S. Highway 321 following the passage of a dry, cold front. (Photo by Columbia Record.)

Initially, the south head moved toward Gaston at about the same rate of spread as did the north head. However, the entire run into the outskirts of Gaston averaged only 0.5 m.p.h. because of the plowed fields and several small lakes and ponds on the outskirts of the town. Fire intensity ranged from 1,000 to 1,200 B.t.u. per second per foot of the fire front. At 2130 EST, the fire was observed putting up a heavy shower of burning embers 300 to 500 feet in the air; and it was feared that it would spot into the town of Gaston. Suppressive action, however, contained the fire at this time.

Shortly before 1800 EST, weather radar at Charleston and Columbia detected a line of thunderstorms oriented along a northeast-southwest line approximately 15 miles southeast of the fire area. At 2020 EST, Fire Laboratory personnel observed lightning in the vicinity of the fire. It was thought that these thunderstorms had formed over the fire in the cold air behind the front. Personnel at the South Carolina Forestry Commission later reported that thunderheads had appeared over other fires in the area and that some rain had fallen. However, no rain was observed in the Gaston area.

By 2020 EST, the north head apparently was at its peak intensity, estimated at 10,000 to 12,000 B.t.u. per second per foot of fire front, and had built up a substantial convection column. At 2045 EST, a thunderhead was observed directly over the north head of the fire as it was crowning through a pine plantation. Observers both at the fire and at the Columbia Airport, 8 miles away, reported that the flames appeared to be drawn upward towards the base of the cell and that occasional flame flashes illuminated much of the cloud.

The high rate of spread and buildup in the fire's intensity after nightfall is rather unusual. However, such phenomena following a frontal passage have been reported; for example, on the previously mentioned Buckhead Fire which occurred in north Florida. The Buckhead Fire started on the afternoon of March 24, 1956, and burned as a prefrontal or warm-sector fire, traveling slightly south of east and averaging 1.7 m.p.h. By 1830 EST, after burning an estimated 4,000 to 5,000 acres, the fire quieted down; but at 2110 EST, immediately after a cold frontal passage, the Buckhead Fire started its major run. At this time the wind veered from the west to the north-northwest, the fire increased in intensity, and the right flank became a series of high-intensity heads traveling rapidly in a southerly direction. During a 10- to 12-hour period following the cold front passage, 90,000 acres were burned.

By 2130 EST, the rate of spread of the Gaston Fire had decreased to 0.6 m.p.h.; and fire intensity decreased to 1,200 to 1,500 B.t.u. per second per foot of fire front. Crowning was no longer evident except for fire flashes up into single trees. Several fire whirls 1 to 2 feet in diameter and up to 15 feet in height were observed (fig. 6). Small windborne sparks were carried out in front of the fire up to 1,000 feet, but they caused no significant control problems. This change in fire behavior coincided with significant changes in the weather after 2130 EST. The relative humidity rose to 40 percent, and the windspeed decreased from 15 to 10 m.p.h. at the Columbia Airport with a slight change to a more northerly direction. The thunderhead over the fire had also dissipated by this time.

The north head was contained at 2330 EST along Old Pine Plane Road. Some very short-distance spotting of less than 100 feet was observed from the backfire along the road. Small windborne sparks were observed blowing across the road, but any that caught fire were quickly extinguished. A further decrease in the windspeed and a sharp shift to the southwest caused the fire to flank into the road rather than hitting it head on. This was an important factor in containing this section of the fire.

Saturday, April 2, 1966

After midnight the winds slackened to 5 to 7 m.p.h. and continued from the southwest quadrant. Shortly after sunrise, the winds increased and moved back to the northwest so that by 0800 EST they were blowing from 280° at 15 m.p.h.

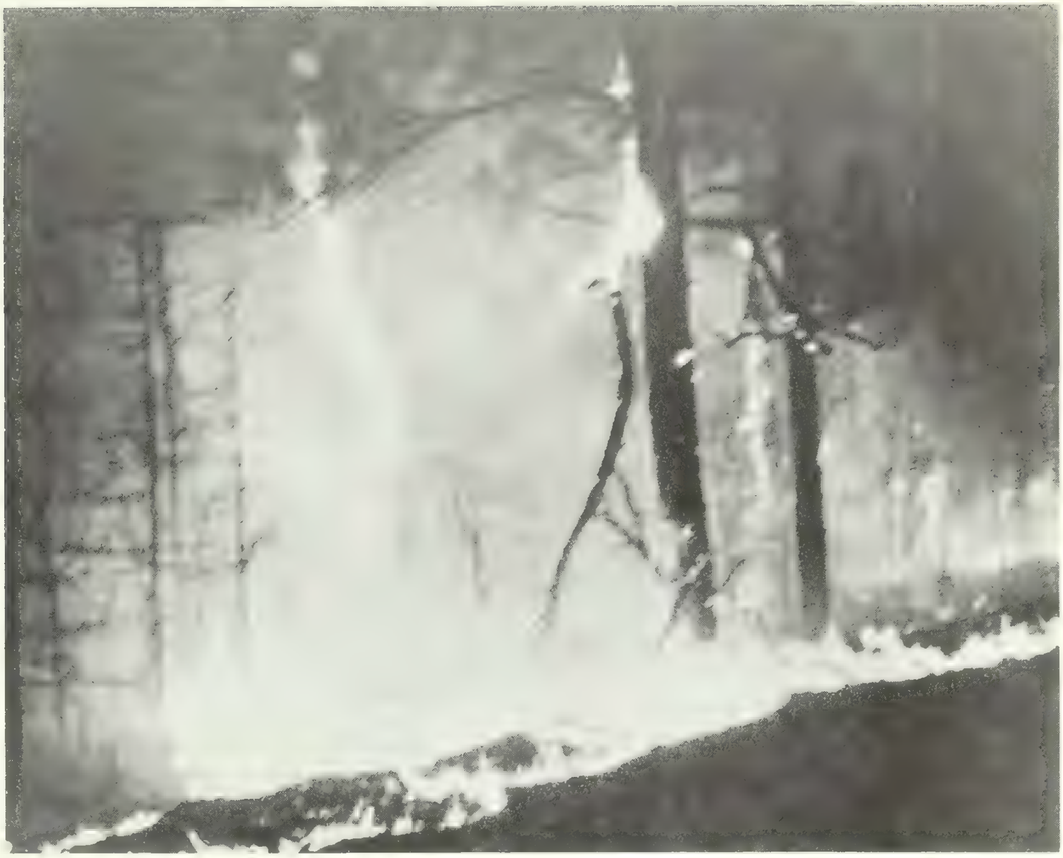

Figure 6.--A fire whirl observed on the north head of the Gaston Fire at 2300 EST on Friday, April 1, 1966.

The second day's run began shortly after 1100 EST when the north flank along the Seaboard Railroad broke away (fig. 7). Many small fire whirls, in combination with a strong surface wind gusting to 25 m.p.h. and a relative humidity of 28 percent, contributed significantly to the fire's escape (fig. 8). Fuel moisture was 3 percent on the 8-100-0 danger system.

The Edmund Fire burned into the rear northwest corner of the Gaston Fire area at 1130 EST but did not affect the behavior of the Gaston Fire (fig. 7).

By 1130 EST, the Gaston Fire was making another major run and had crossed U. S. Highway 321, heading on a narrow front in an easterly direction. The head was estimated to be less than one-half mile wide.

Observations of the smoke column indicated that convective activity was limited and that only a small convection column had built up. The smoke column showed an unusual configuration by going straight up to 1,200 to 1,300 feet, moving horizontally for 3 to 4 miles and then billowing up again to about 2,000 feet.

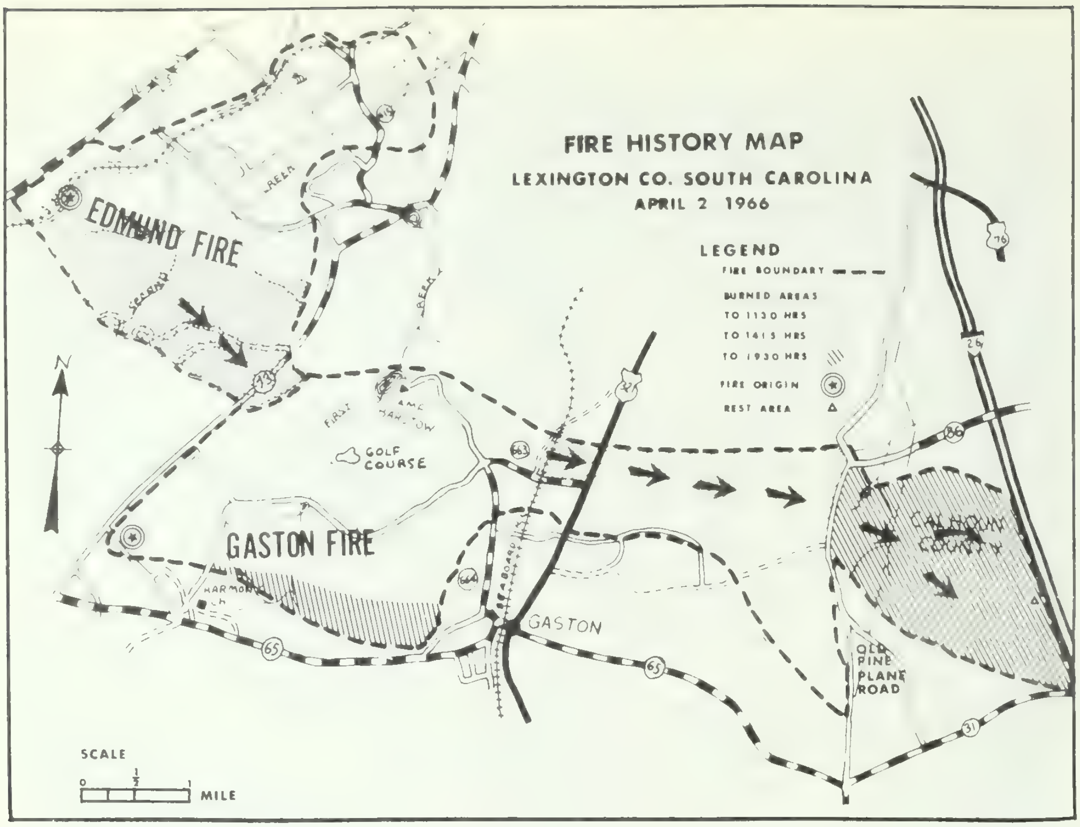

Figure 7.--Fire spread of the Gaston and Edmund Fires on Saturday, April 2, 1966.

Figure 8.--On the afternoon of April 2, the fire, driven by high winds, reached intensities up to 3,000 B.t.u. per second per foot of fire front.

A pibal run at 1258 EST showed a wind maximum of 48 m.p.h. at 1,300 feet and a minimum of less than 20 m.p.h. at 2,100 feet. The high windspeed at the jet point over the fire and the small depth of decreasing windspeed above this jet point probably restricted the development of the convection column.

Rate of spread over a 2-mile portion of this run averaged 1.2 m.p.h., and fire intensity ranged from 2,500 to 3,000 B.t.u. per second per foot of fire front. The head widened out slightly to three-fourths of a mile during the run. Spotting was heavy for several hundred yards directly in front of the main head. At 1400 EST, the fire spotted across a powerline right-of-way about 1,000 feet west of Old Pine Plane Road, which had been backfired from a series of plowlines. The backfire had only moved in about 50 feet when it was met by the head. The fire then jumped Old Pine Plane Road heading in an easterly direction toward Interstate Highway 26 (fig. 7).

Rate of spread decreased to 0.7 m.p.h. after the fire had crossed Old Pine Plane Road. By 1600 EST, the main head had developed two prongs, a phenomenon typical of high intensity wildfires. The south prong began traveling in a more southerly direction toward the intersection of Interstate 26 and County Route 31. The north prong continued on directly toward the Interstate. The two prongs had almost reunited when the north prong of the fire reached Interstate 26 at 1700 EST. Although spotting across the right-of-way did occur when the north prong met a backfire, the spots were suppressed and fire was contained at this point. The south prong, which was traveling in a southeasterly direction at a slow rate of spread, flanked into Interstate 26 and was contained shortly after 1900 EST.

A slackening of the wind shortly after 1700 EST was a major factor in containing the fire at Interstate 26. A pibal run taken at 1716 EST showed that the winds aloft had fallen off significantly and gave no evidence of the low-level windspeed maximum which had persisted during the previous 36 hours. It is doubtful that the fire could have been contained at Interstate 26 if this falling off of wind had not occurred.

Plowed fields adjacent to the Interstate right-of-way helped to contain the fire. After the windspeed decreased, spotting was reduced to very short distances.

During the second day's run from 0900 to 1800 EST, wind varied in direction from 280° to 300°, and in speed from 12 to 15 m.p.h. with gusts as high as 25 m.p.h. Temperatures reached only 65° F., 20° below the maximum reading of the previous day. The relative humidity fell to a low of 20 percent, 5 percent below Friday's low.

Both fires presented no further problems; and mopup was completed Sunday night, April 3, when rain fell.

FIRE CONTROL EFFORTS

Friday, April 1, 1966

The first fire control officer to view the Gaston Fire was an aerial observer who flew over the fire at 1345 EST on his way to scout two other fires in the vicinity. Flying back over the fire 15 minutes later, he estimated the size at 1,000 acres. Because of the unusually heavy fire load in District 5 and throughout the state, neither equipment nor personnel were available to send to the fire until nearly 2 hours after its origin. The first piece of equipment was an emergency standby tractor-plow from Columbia which arrived at 1445 EST and began plowing a firebreak along the fire's east flank. Realizing that the fire's head was far in front of him and that the head could not be caught, the tractor operator decided to transport his tractor to a more advantageous location where he could make a direct attack on the head. However, after seeing that the head was moving too fast and was too intense for him to cope with alone, he decided to begin plowing firebreaks around buildings being threatened along the fire's western flank.

A second tractor-plow unit arrived at the fire at approximately 1500 EST and began plowing on the eastern flank close to the head of the fire.

Overhead arrived on the scene at 1515 EST and began scouting the fire with the assistance of the aerial observer. As the cold front moved through the area, the fire split into two heads and changed from an east-northeast direction of travel to an east-southeast direction. The north head, moving at a high rate of spread (3 m.p.h.), spotted an estimated one-half mile across U. S. Highway 321. The south head, which was slowed by plowed fields and some small lakes, moved toward the town of Gaston.

More mechanized equipment arrived at short intervals until there were nine tractor-plows in operation. Virtually all equipment used on the fire had arrived by 2300 EST. In addition, there were many cooperators on the fire with mechanized equipment such as bulldozers and farm tractors with harrows.

The first concerted control action took place at 2100 EST west of Gaston on the south head of the fire (fig. 3). A firebreak was plowed along the south flank and backfired. The south head of the fire was stopped as it ran into large plowed fields on the west edge of Gaston at 2130 EST.

No control action was possible on the north head between 1800 and 2200 EST. The fire had during that time made a run of nearly 5 miles.

The attack on the north head was made along Old Pine Plane Road at 2200 EST (fig. 3). Two tractor units plowed double firebreaks parallel to the road 100 to 200 feet west of the embankment and at right angles to the approaching head. Backfiring was done along the road wherever the tractors could not complete firebreaks before the fire arrived. A slight northerly shift in the wind caused the head to flank into the road and veer into an open field. The firebreaks held and at 2330 EST the fire was stopped. Some spotting occurred across the road, but the spots were extinguished without difficulty.

Equipment immediately began plowing along the flanks to try to get a complete firebreak around the fire perimeter before the next morning.

Saturday, April 2, 1966

The aerial observer was on hand early the next morning directing men and equipment to potential hotspots and breaks in the line. The fire seemed to be under control around the entire perimeter and little trouble was experienced in containing the few excursions which occurred. At 1130 EST the Edmund Fire burned into the Gaston Fire but caused no difficulty (fig. 7). At the same time, a spot fire started (possibly from a burning telegraph pole) on the north flank of the fire just east of the Seaboard Railroad right-of-way and began moving rapidly toward U. S. Highway 321. A tractor-plow and a bulldozer put a firebreak along the north flank of the spot fire, but a number of small whirlwinds developed along the firebreak and scattered firebrands outside the line. This outbreak burned along the north flank of the previous day's burn. As the fire reached U. S. 321, it spotted across the highway. The dense smoke and intense heat prohibited direct attacks on these spot fires. The spot fires quickly burned together, forming a head which ran slightly south of east at an average of 1.2 m.p.h. A stand was made at a powerline paralleling Old Pine Plane Road and approximately 1,000 feet to the west of it. A backfire was set, but it had only burned in 40 to 50 feet when the head fire met it. A flareup and spotting resulted, and the fire jumped the powerline right-of-way. Soon thereafter, the fire crossed Old Pine Plane Road, heading in an easterly direction.

The next stand was made on Interstate 26. From the air, it appeared that the fire would hit Interstate 26 someplace between a rest area and the intersection of County Route 31, 2 miles to the south. The head formed two prongs at about 1500 EST, one going toward the rest area, and one heading toward the intersection of I-26 and County Route 31 (refer to fig. 7). A farm tractor was used to harrow the grass right-of-way on the west side of Interstate 26. Two 1,200-gallon seed sprayers filled with water and several plow units and bulldozers stood by along the Interstate right-of-way and County Route 31 in case the fire spotted across either highway. Unauthorized personnel backfired from the rest area at 1630 EST. At about the same time, the wind shifted more to the northwest; and the fire flanked into Interstate 26. The prongs of the head had almost rejoined by 1700 EST when the fire hit the Interstate. The backfire from the rest area also met the northeastern flank of the fire at this time. The fire spotted across Interstate 26 onto the grass right-of-way in several places, but the tankers extinguished the flames.

On the advice of the aerial observer, at 1750 EST backfiring was initiated north along Interstate 26 from the intersection and west along County Route 31 from the intersection. The wind had died down to 5 to 8 m.p.h., and the fire's rate of spread had decreased. By 1930 EST, the whole fire had quieted down and no difficulties in control were reported. Many of the plow units were called off the fire at this time to give the operators a chance to eat and rest. On Sunday morning they were back on the job and continued mopping up until Sunday night when 0.84 inch of rain fell on the area.

FIRE EFFECTS

Strikingly evident throughout the burned area was the complete consumption of the fine fuels and the exposure of mineral soil. As a result, the soil may be susceptible to erosion, but it is difficult to ascertain how much will occur. The sandy soil typical of the area has a high infiltration capacity; however, should this capacity be exceeded, soil movement will result.

Damage to manmade structures was limited to the destruction of 21 cabins in the boy scout camp, two unoccupied dwellings, a number of utility poles, and several railroad ties.

A year after the fire, on April 17 and 18, 1967, a survey of the area was made to determine the extent of the fire damage to the various cover types.

In the young slash pine plantations, survival was amazingly high (estimated at greater than 90 percent), but "brooming" around the terminal leaders had developed on 10 to 15 percent of the trees (fig. 9). The form that the "broomed" trees will eventually have is of concern, as any economic losses resulting from the lowering of the quality of the trees should be charged to the fire.

An unidentified species of tip borer[7] and the pales weevil (Hylobius pales [Herbst.]) have infested the area and are doing considerable damage. The pales infestation is thought to have originated in adjacent areas where salvage operations have been carried out, but it is possible that the weevils were attracted directly to the area immediately after the fire by the scorched needles.

A testimony to the severity of the fire which these young slash pine trees withstood is the damage found on many of the stems (fig. 10). Callus growths are already evident and should heal over the injuries in a short time.

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[7] No insects were actually found, but it is suspected that the damage was caused by the Nantucket pine moth (Rhyacionia frustrana [Comst.]).

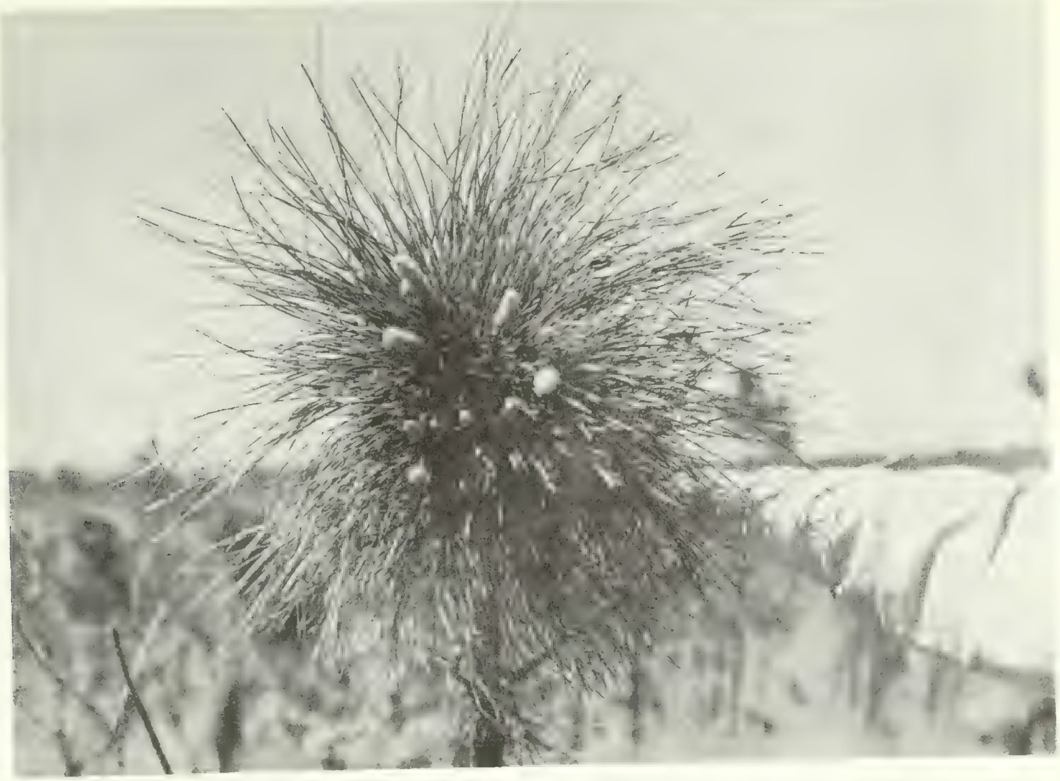

Figure 9.--"Brooming" on young slash pine.

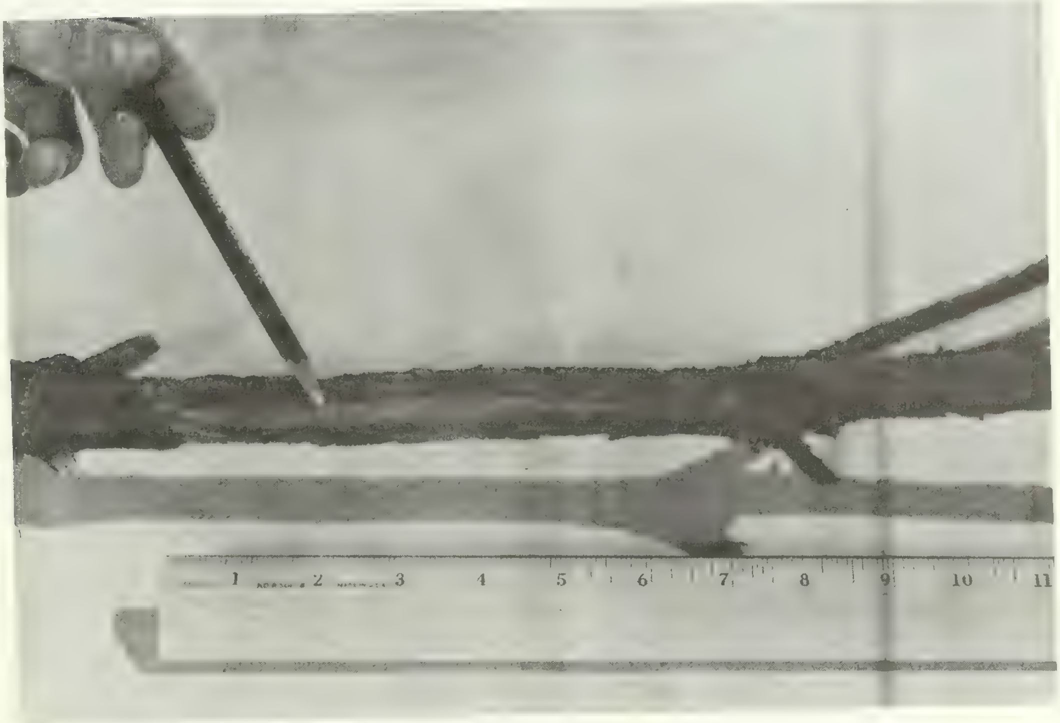

Figure 10.--Stem damage caused by fire on young slash pine. Note the healing which has taken place during this first year.

The high rate of survival in the young slash pine plantations is attributed to the light surface fuels which were present when the fire occurred. Even though extensive scorch and some consumption resulted, the fire moved so fast (4 chains per minute) that the cambial temperatures around the entire circumference of the stems did not reach a lethal level.

In the immature slash pine plantations, destruction was nearly complete; and, in the natural longleaf stands, the younger trees up to pole size were killed because of the bushy undergrowth. The mature longleaf pines which were severely scorched showed little effects of the fire other than blackened trunks.

In the stands of longleaf pine-scrub oak and in the scrub oak stands, the fire killed the aerial portions of the oaks (some as large as 6 inches in diameter at ground level), but subsequent basal sprouting was profuse. As many as 25 sprouts were counted on a single root collar (fig. 11).

In summary, damage appeared to be much less than estimated immediately after the fire, except in the immature slash pine plantations. Effects on the young slash pine will have to be evaluated after several more growing seasons in order to confirm the permanence of damage.

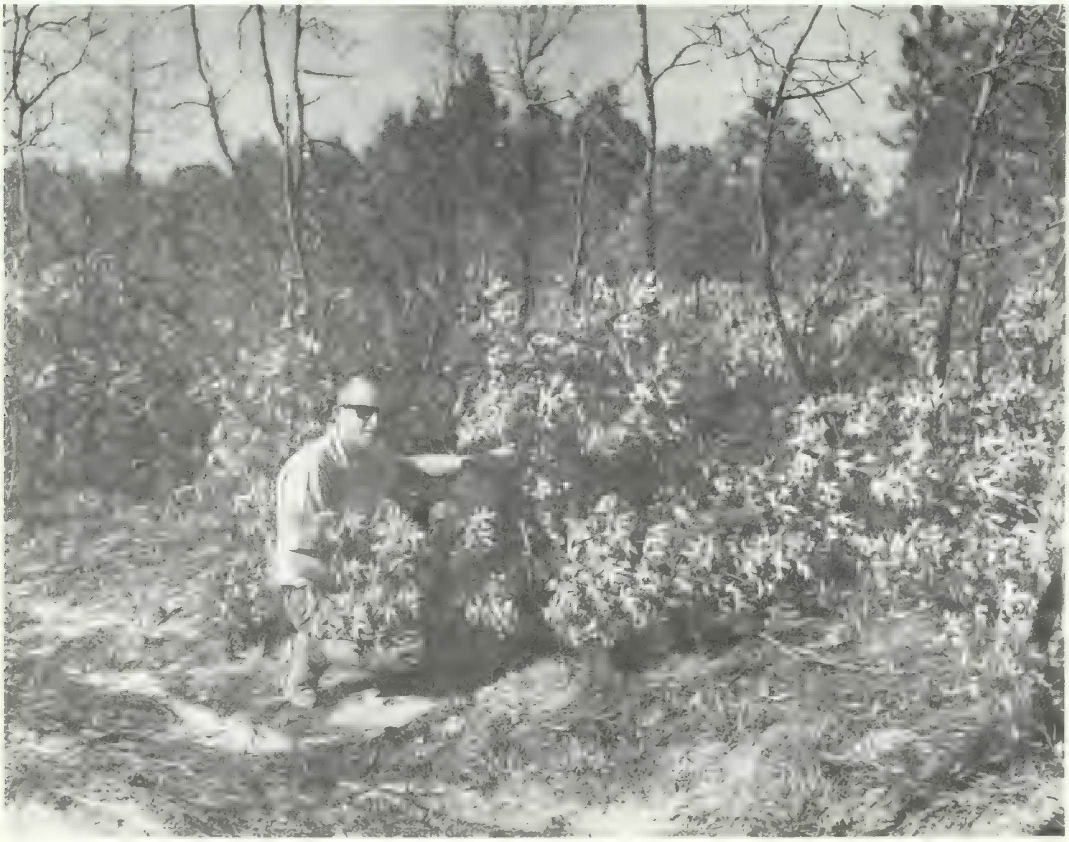

Figure 11. --Basal sprouting on fire-killed scrub oak.

SUPPRESSION FIRING[8]

Under extreme burning conditions when conventional control techniques are ineffective, suppression firing may well be the only alternative which has any chance of success. In such situations, suppression firing might be considered dangerous or hazardous, but it is at these times that aggressive, perhaps unconventional, tactics are warranted. If sufficient manpower and the appropriate equipment had been available, the Gaston Fire would have presented such an opportunity: it was intense and fast moving--the suppression force mainstay, the tractor-plow, was effective only on the rear and flanks of the fire--and it was burning in an area crisscrossed by a number of existing firebreaks.

Because this report presents detailed information concerning the behavior of a wildfire that defied normal control action, it provides an excellent opportunity to illustrate, as a training exercise, when and where suppression firing might have been applied in an actual fire situtation. The success of the techniques of suppression firing in these situations is a matter of conjecture, and in this instance merely hindsight; but it may at the very least stimulate the reader's thoughts in that direction.

There were two opportunities during the Gaston Fire when suppression fires might have been used. The first was on Friday afternoon between 1800 and 1900 EST. At 1600 EST, the fire was traveling in an east-northeast direction heading for the Camp Barstow area (fig. 3). The wind shift that was expected with the cold front passage later in the afternoon would change the direction of travel from east-northeast to a more southeasterly course.

As time was of the essence, principal scouting would have been left to the aerial observer. He could have kept a critical watch on the head and reported when it changed direction.

After the passage of the cold front and the resulting shift in the fire's direction, action might have been taken to the east along a railroad right-of-way running north-south (fig. 12). As it actually happened, the fire changed direction shortly after 1800 EST, crossed the Camp Barstow Road north of the intersection of Routes 663 and 664, and then crossed the railroad along and to the south of Route 663 at approximately 1830 EST (fig. 3).

Strip head fires could have been used to quickly burn out a wide area to the west of the railroad right-of-way south of Route 663 (fig. 12). The right-of-way would have served as a firebreak, and a strip 25 feet wide could have been burned out with a head fire. As many additional strips could have been burned as time permitted, thereby increasing the width of the break until a safe width (dependent on fire behavior) had been reached.

---

[8] Suppression firing is the application of fire to speed the final control of free-burning wildfires. Suppression fires may be used to accomplish tasks such as the widening and strengthening of firebreaks, the removal of dangerous fuel concentrations, etc.

The firing of the strips would have been staggered; as soon as the first strip began to burn out, the second strip would have been started, and so on with each additional strip.

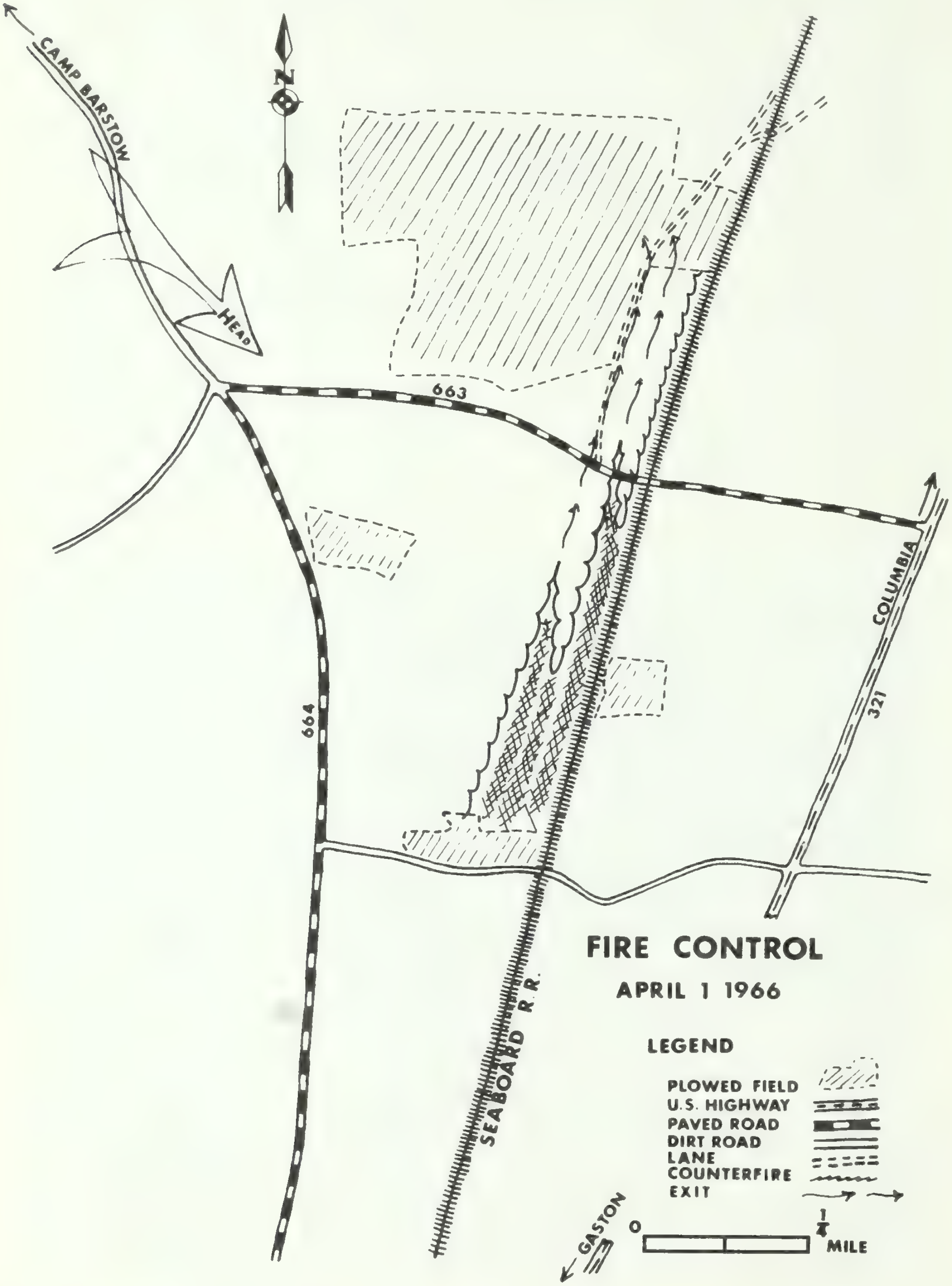

Figure 12.--Proposed use of strip head fires for fire control purposes along railroad right-of-way shortly after 1800 EST on Friday, April 1, 1966.

Ideally, the final strip would have been set from a firebreak so that no backfire was left. Under the prevailing weather conditions, a backfire meeting the head of the main fire might have caused a flareup and more spotting than was already occurring.

Volunteers would have been deployed to the east of the railroad to watch for spot fires both from the strip head fires and finally from the main fire.

On Saturday afternoon between 1130 and 1415 EST, another opportunity arose when suppression fire might have been used during the fire's major run. A stand could have been made at Old Pine Plane Road toward which the fire was heading, and did, in fact, eventually cross (fig. 13).

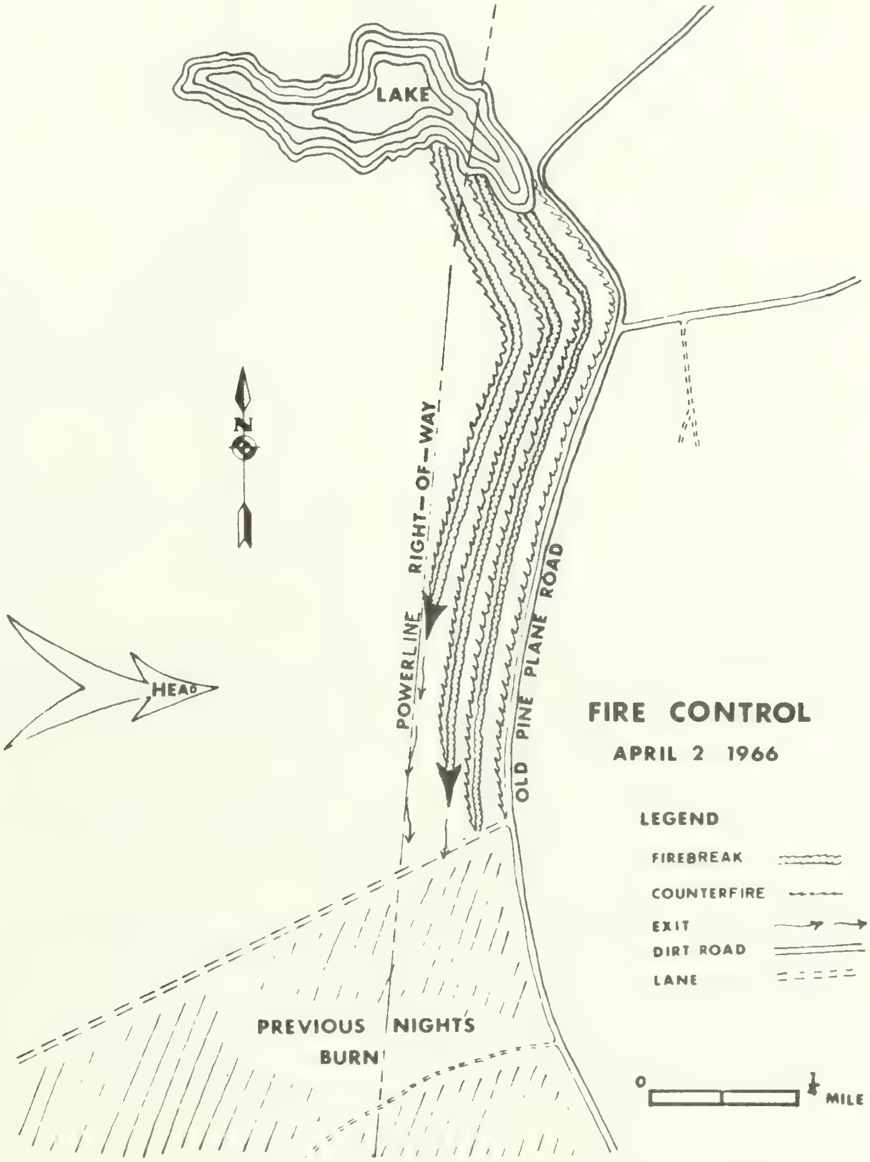

Figure 13.--Proposed use of strip backfires for fire control along Old Pine Plane Road, Saturday afternoon, April 2, 1966.

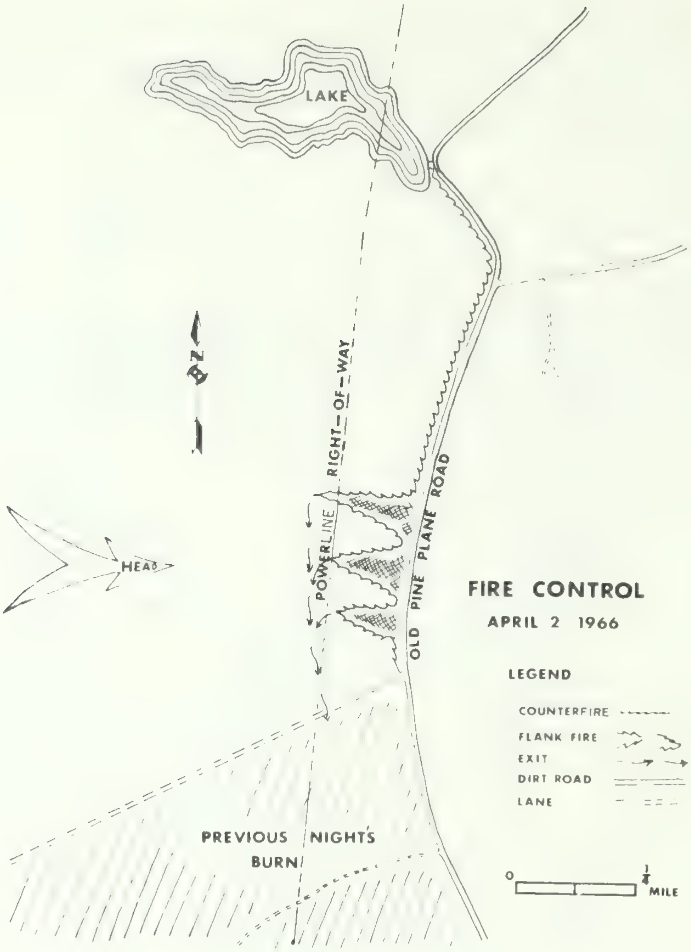

Figure 14.--Alternate proposal of strip flank fires along Old Pine Plane Road, Saturday afternoon, April 2, 1966.

Several firing techniques could have been employed at this point: strip head fires, strip backfires, or flank fires. As tractor-plows were available, strip backfires could have been used as a conservative technique. The anchor points could have been the previous night's burn on the south and a large lake approximately 1 mile to the north (fig. 13).

If strip backfires had been selected, the initial firing would have been south along the road. At the same time, multiple firebreaks would have been plowed and fired 1 to 2 chains apart and parallel to the road. If strip head fires had been used, firing would have been similar to the foregoing example for Friday afternoon. Strip flank fires could have been run into the wind toward the approaching head from either a backfire along the road or from the strip backfires (fig. 14). This would have been the most difficult firing technique to use from the standpoint of timing and safety. Firing of strips would have to be staggered so that the northernmost flank would be the most advanced. The personnel doing the firing could then have exited safely to the south into the previous day's burn. Volunteers would have been deployed east of Old Pine Plane Road to watch for spot fires.

SUMMARY

On April 1 and 2, 1966, the Gaston Fire burned a total of 7,431 acres in South Carolina, including 5,436 acres of forest land in the sandhills country. The fire reached its peak intensity following the passage of a dry, cold front.

The fire danger in the sandhills was rated as extreme on both the 8-100-0 and the National Fire Danger Rating Systems. Several stations reported buildup and burning indexes of 100 for both the 1st and 2nd of April on the 8-100-0 system. The National Fire Danger Rating System showed buildups above 70 and spread indexes between 50 and 100.

During the warm sector burning period (1230 and 1800 EST, Friday, April 1), the fire developed two heads after running into a golf course, each head burning along a narrow front in an east-northeast direction. The cold front caused the wind to shift from 240° to 290°. Both heads picked up in intensity and began running in an east-southeast direction. The north head was the more intense; it ranged from 6,000 to 11,000 B.t.u. per second per foot of fire front. Plowed fields and small lakes and ponds in the path of the south head prevented it from reaching a comparable intensity.

Rate of spread increased from 1.7 to 3 m.p.h. on the north head immediately following the frontal passages. The rate of spread decreased to 0.6 m.p.h. over the next 4 hours as atmospheric conditions ameliorated. On the second day's run, the rate of spread averaged 1.2 m.p.h.

Spotting contributed greatly to the fire's high rate of spread and to the ease with which it crossed firebreaks during major runs. It was estimated that spotting occurred up to one-half mile ahead of the fire during Friday's major run and up to one-fourth mile on Saturday.

Fire whirls were observed on several occasions. Numerous small fire whirls, estimated by the fire boss to be 18 to 24 inches in diameter and 4 feet in height, caused spotting over the firebreak. This spotting resulted in the fire's escape Saturday morning.

Daytime fine fuel moistures (measured) ranged between 5 and 10 percent. Available fine fuel was estimated to be nearly equal to the total fuel.

Windspeed was the paramount meteorological factor influencing fire behavior both before and after the frontal passage. Average windspeeds were 15 m.p.h., with gusts exceeding 25 m.p.h. Hourly spread indexes (National System, timbered areas) ranged from 33 to 99 on Friday and from 23 to 79 on Saturday.

On both days, the minimum relative humidities were below 25 percent during daylight hours. Of particular significance were the low humidities recorded Friday night after the frontal passage. The relative humidity reached a maximum of only 54 percent that night.

APPENDIX

WEATHER SYNOPSIS

Background - Buildup Phase

Throughout the southeastern United States, the last 3½ weeks of March 1966 were characterized by below-normal rainfall and relative humidities. By the end of the month, fire danger was in the severe to extreme categories from Tennessee and Virginia to the gulf coast; and fire incidence was high.

During this buildup period from the 5th of March to the 1st of April, the upper-level, long-wave ridge maintained an average position well to the west of the Appalachians with the result that the winds aloft over the Southeast held generally from the northwest quadrant. In the lower levels, the Bermuda high has centered in the eastern Atlantic, far removed from its more normal position off the east coast of the United States.

The effect of this pattern was to steer a series of dry, polar high-pressure cells from the interior of North America across the region. These highs prevented the influx of moisture from the Gulf of Mexico which is normally associated with widespread rains in this section of the country.

The leading edge of each of the migratory, high-pressure cells was marked by a cold front; but, because of the lack of an adequate accumulation of moisture in the modified polar airmass to the south and east of the system, precipitation was light and scattered.

The U. S. Weather Bureau observing station at the Columbia Municipal Airport, which is located 8 miles north of the Gaston Fire area, reported only 2.23 inches of rain during the month of March. This was the driest March since 1955, when 2.00 inches was recorded. Of the 2.23 inches in March 1966, 2.09 inches fell on the 3rd and 4th, 0.12 inch on the 15th, and 0.02 inch on the 24th. The trend in the buildup index (National Fire Danger Rating System), as well as the occurrence of rainfall and cold frontal passages during the period from March 3 through April 3, was computed (fig. 15). The average maximum daily temperature was only 1° below the climatic average, but the average relative humidities were significantly lower (table 3).

In addition to the lack of rainfall and the meteorological drying conditions of near average maximum temperatures and below average humidities, the inability of the sandhills soils to retain water contributed significantly to the extremely dangerous fuel conditions found at Gaston on the 1st of April.

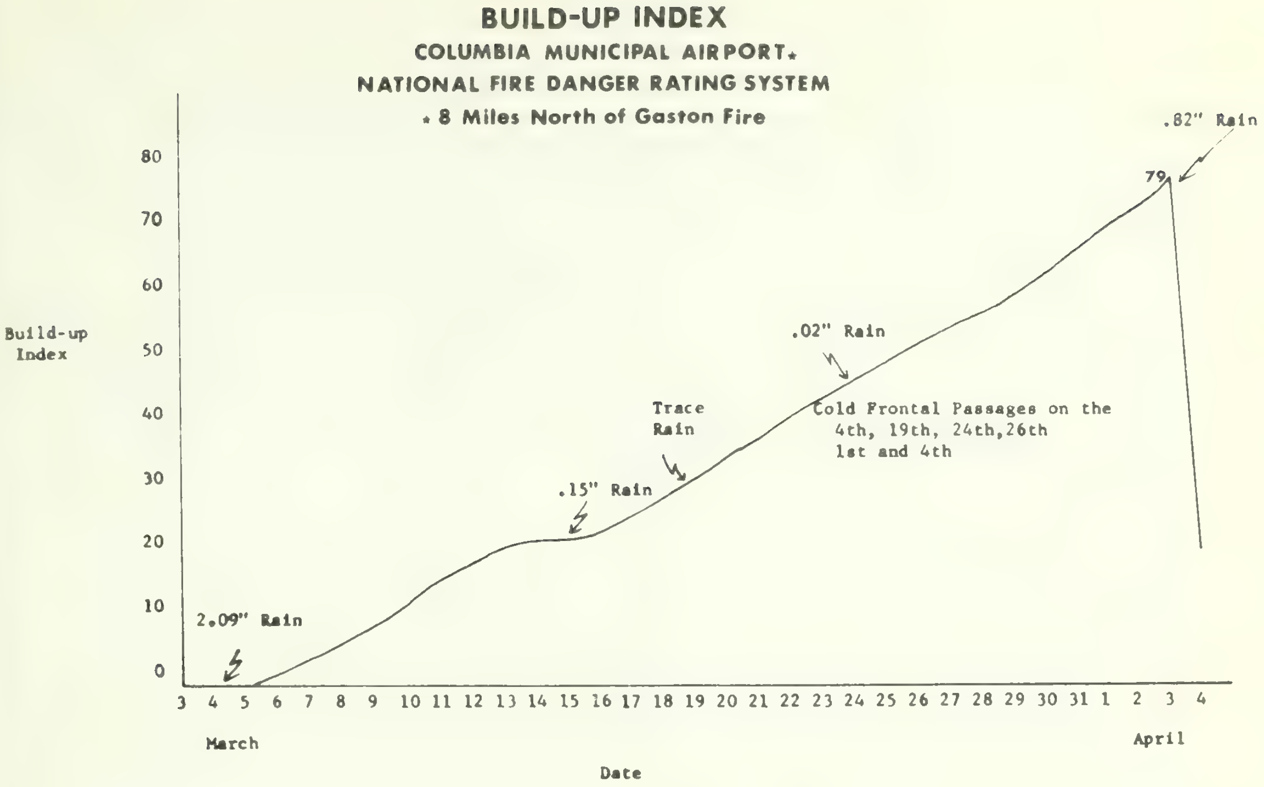

Figure 15.--Buildup Index, National Fire Danger Rating System, for the period March 3 through April 3, computed from data taken at the Columbia Municipal Airport.

Table 3.--A comparison of certain weather parameters for March 1966 with the average March conditions

Columbia Municipal Airport

Date	Average maximum temperature	Average minimum temperature	Precipitation	Relative humidity			
				0100	0700	1300	1900
	°F.	°F.	Inches	- - - -	Percent	- - - -	
March 1966	65.6	38.0	2.23	72	80	38	45
March average	66.5	42.3	4.26	70	83	48	57

Fire Weather

On the 31st of March, a large low-pressure center was intensifying over the north-central United States. A polar, continental airmass covered the eastern seaboard, holding temperatures and humidities generally below seasonal normals. In the Columbia area, the winds were northerly and the temperature stayed in the 60's.

By Friday morning, the previously mentioned low was at its maximum intensity over the Great Lakes; and a cold front extended out of the low across western Pennsylvania and the south along the Appalachians. The high-pressure cell which had covered the eastern United States the day before had moved off the coast and was weakening rapidly under the influence of the Great Lakes storm and another in the Atlantic south of Greenland.

The raobs[9] taken at Athens, Ga., Greensboro, N. C., and Charleston, S. C., all showed strong southwesterly winds in the lower levels (fig. 16) as well as marked warming. The lapse rates above the radiation inversion were dry adiabatic, indicating that thermally induced turbulence later in the day in the lowest few thousand feet was very likely.

By 1000 EST, the U. S. Weather Bureau Station at the Columbia Airport was reporting winds gusting in excess of 25 m.p.h. and a temperature of 74° F., 16° warmer than the 1000 EST reading of the previous day. By noon, shortly after the start of the Edmund Fire and just before the start of the Gaston Fire, the temperature was 81° F. and the humidity was 26 percent.

By 1300 EST, a pressure trough had formed behind the cold front in the lee of the Appalachians. This trough served to tighten the pressure gradient across the state, causing the front to slow and the winds in the Gaston area to increase (fig. 17).

That afternoon at Gaston, the temperature reached a high of 86° F., and the wind continued out of the southwest with gusts as high as 40 m.p.h. One gust of 46 m.p.h. was recorded at the Columbia Airport just before 1600 EST.

A pibal run taken at 1740 EST showed a steady increase in the winds with height to near 1,700 feet, where a 49 m.p.h. maximum was located. The winds above that point decreased to a height of at least 3,000 feet, where the run had to be terminated because of the dense smoke (fig. 18).

The cloud cover from noon until 1800 EST was limited to scattered cumulus with bases estimated at 5,000 feet. Vertical development was estimated at only 1,500 to 2,000 feet.

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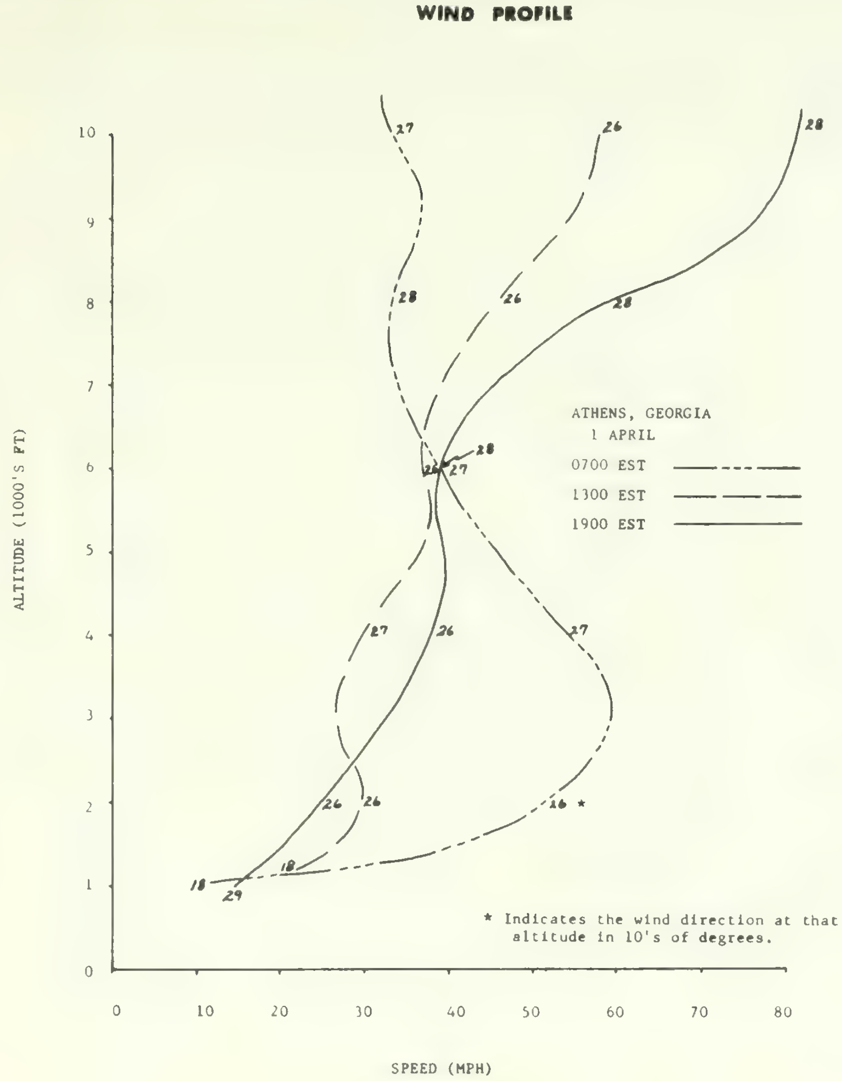
[9] Raob is an abbreviation for "radiosonde observation." A raob consists of temperature and humidity data taken at intervals of height above the ground by a balloon-borne instrument package and transmitted to a ground-based receiver. The winds above the surface can be computed from the data derived from the ground-based receiver, which has a direction-finding antenna.



* Indicates the wind direction at that altitude in 10's of degrees.

Figure 16.--Wind profiles constructed from raobs taken at Athens, Georgia, on April 1, 1966.

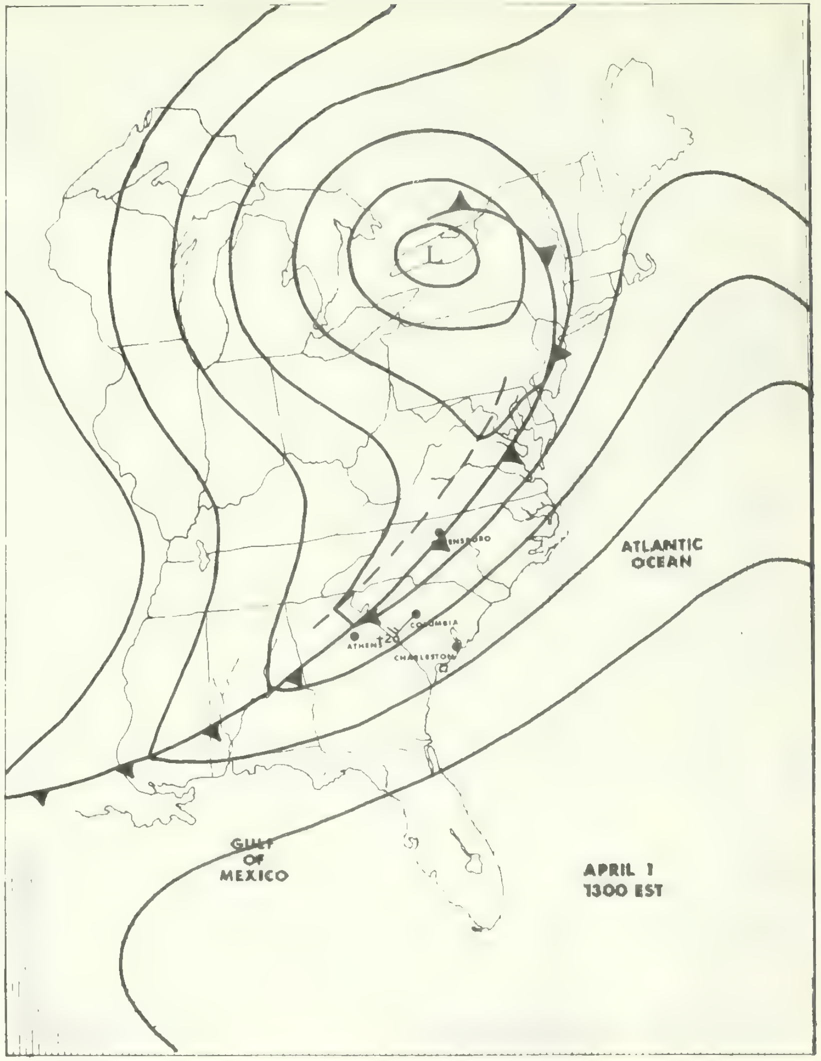


Figure 17.--Surface synoptic features over eastern United States at 1300 EST on April 1, 1966.

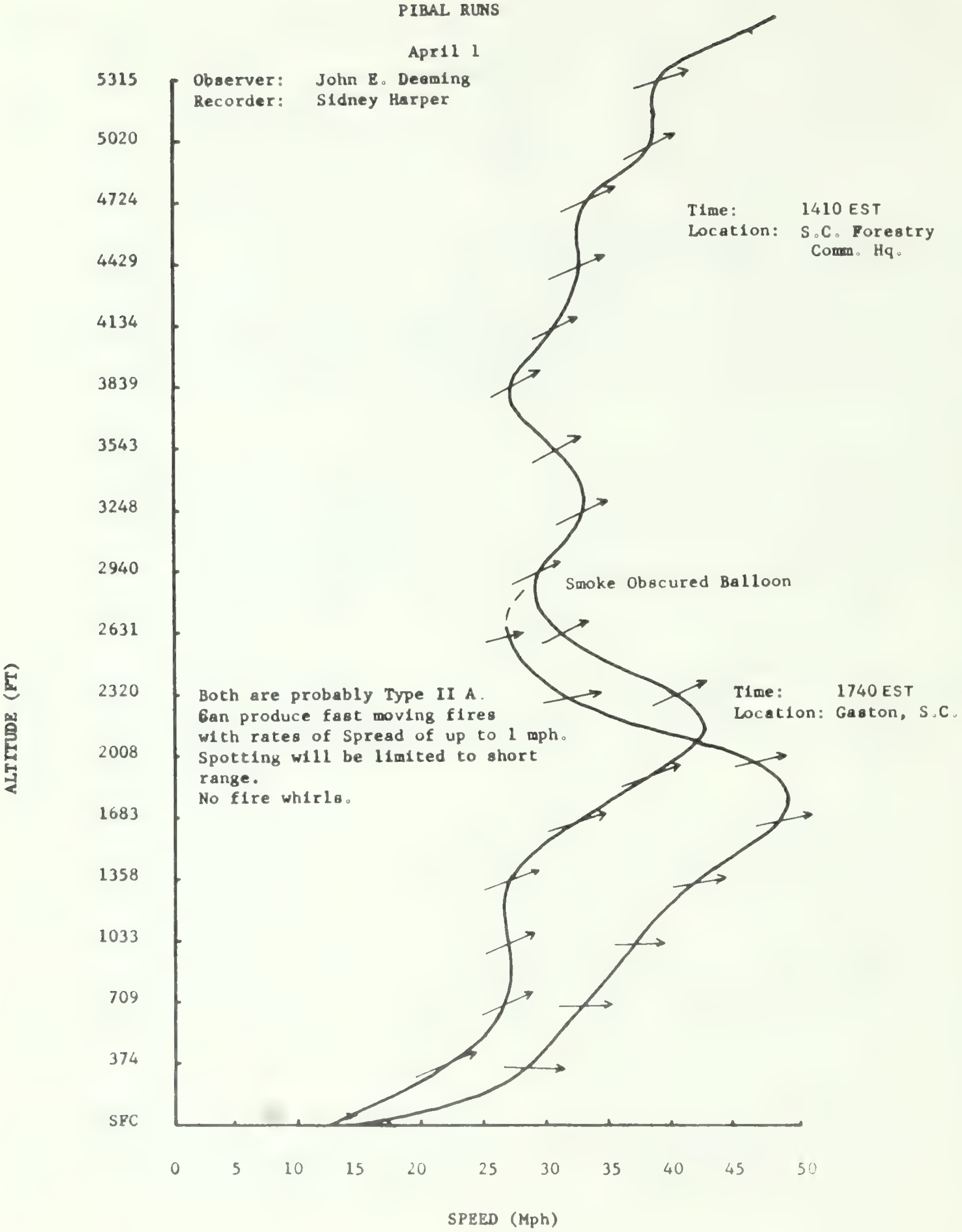


Figure 18.--Wind profiles constructed from pibal data taken near Gaston on April 1, 1966.

Shortly after 1800 EST, the cold front which had moved across the Appalachians during the morning pushed through Gaston (fig. 19). The wind shifted from 240° to 290° and the relative humidity, which had begun increasing in a normal manner, dropped slightly and leveled out. By 2300 EST, the wind had moved around to 320° and decreased to 15 m.p.h. at the airport.[10]

At 1750 EST, weather radar observers at Charleston and Columbia reported a line of thunderstorms oriented northeast to southwest about 15 miles southeast of Gaston. At 2020 EST, Fire Laboratory personnel observed lightning in the vicinity of the fire. It was hypothesized that thunderheads had formed in the unstable air over the fire's head. Personnel of the South Carolina Forestry Commission and the weather radar observer at Columbia later confirmed that thunderheads had formed in the vicinity of other fires in the same general areas during this period.

At 2045 EST, a thundercloud was observed directly over the main head of the fire, which was then crowning through a pine plantation. Observers at the fire and at the Columbia Airport reported that the flames appeared to be drawn up toward the base of the cloud and that flame flashes were causing much of the cloud to be illuminated. One of the witnesses to this phenomenon was the fire-weather forecaster for South Carolina, Jerry Kanupp. He stated that one flareup, which was easily distinguished from the lightning flashes and the reflection of the fire off the smoke column and cloud, seemed to travel up into the base of the cloud as a huge fireball. This fireball probably resulted from the ignition of a concentration of unburned gases. Mr. Kanupp said later that several fire control personnel in the state acknowledged having made similar observations during their careers.

It should be noted here that the phenomenon occurred during darkness, when it was impossible to distinguish between the fire's convection column and the cloud above. In fact, it is most likely that the two were contiguous, as a portion of the moisture needed to build the thunderhead had to come from the water vapor in the convection column. Again, visual confirmation was not possible; but considerable vertical development is suspected because the Charleston radar observer reported that the tops of the cells within the area were above 25,000 feet.

At 0100 EST Saturday morning, the low which had formed in eastern North Carolina 8 hours earlier was moving rapidly northward just off the Atlantic Coast. The parent cyclone had become stationary over the eastern Great Lakes and was filling as the newer low deepened. The pressure trough which was moving east out of the lee of the Appalachians caused the winds in the fire area to back into the southwest (fig. 20).

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[10] The fire-weather forecaster, Jerry D. Kanupp, of Columbia, later received several reports from towers in the western sections of the state that multiple wind shifts followed the passage of the cold front. Several fires in those sections were significantly affected by this erraticism. Mr. Kanupp is investigating the possibility that several small troughs formed in the lee of the mountains and then decreased in amplitude as they progressed eastward. Only the one trough, which is shown on the attached maps, was detected passing through the Gaston area.

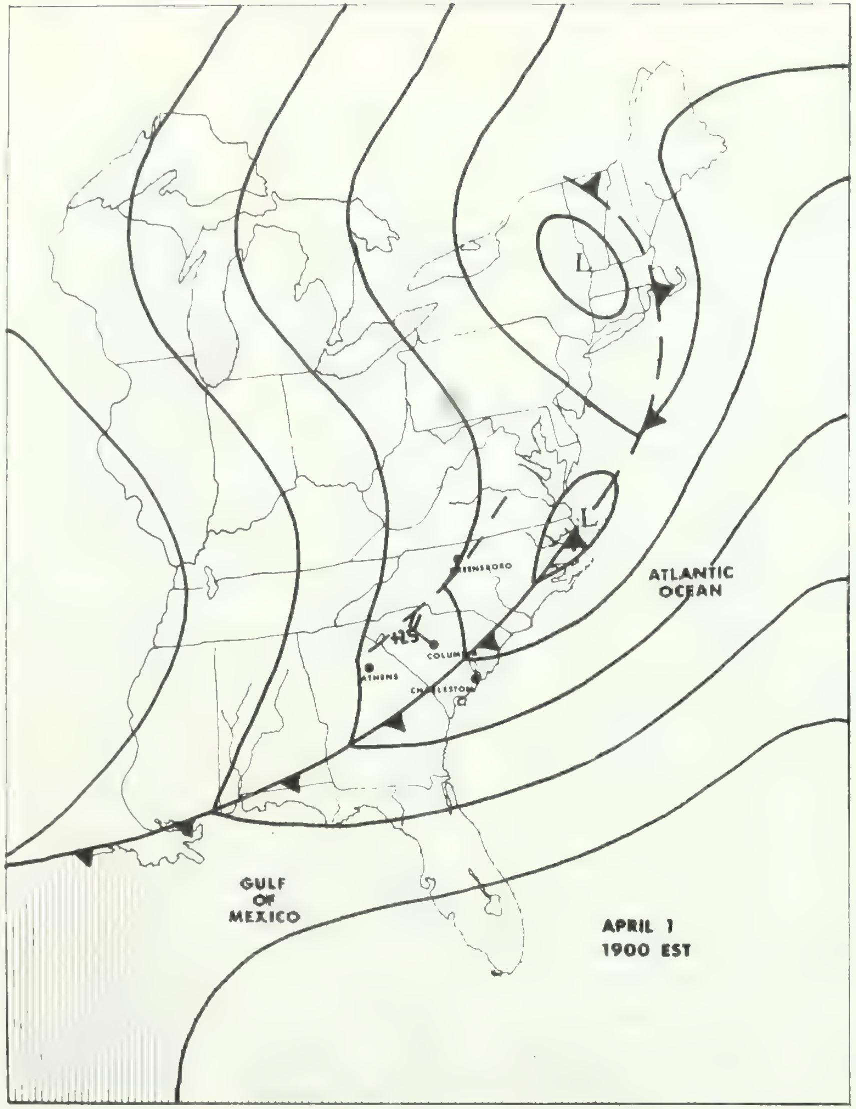


Figure 19.--Surface synoptic features over eastern United States at 1900 EST on April 1, 1966.

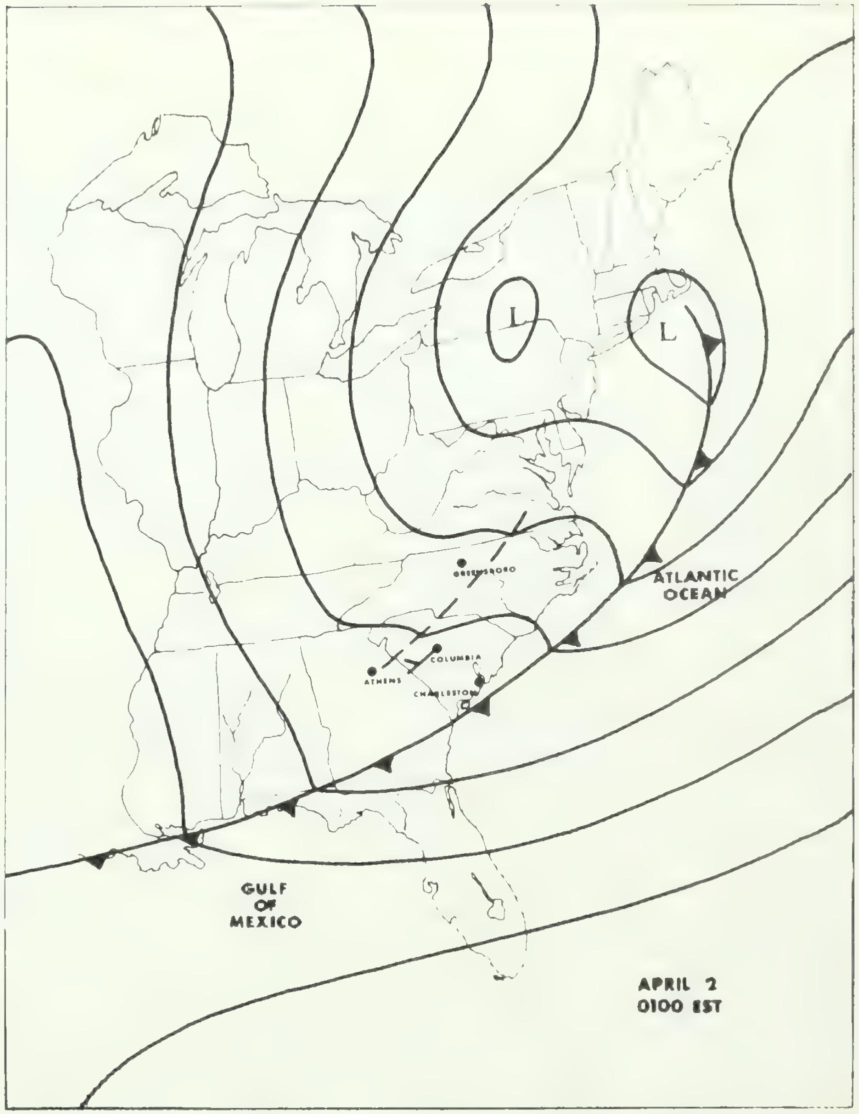


Figure 20.--Surface synoptic features over eastern United States at 0100 EST on April 2, 1966.

By 0800 EST, shortly after the passage of the pressure trough, the winds had veered to 280° and had picked up to 15 m.p.h. From 0900 until 1800 EST, when the second day's run was stopped at the interstate highway, the winds held steady from 280° to 300° at 12 to 15 m.p.h., with gusts to 25 to 30 m.p.h. Again, these wind observations were made at the Columbia Airport (fig. 21).

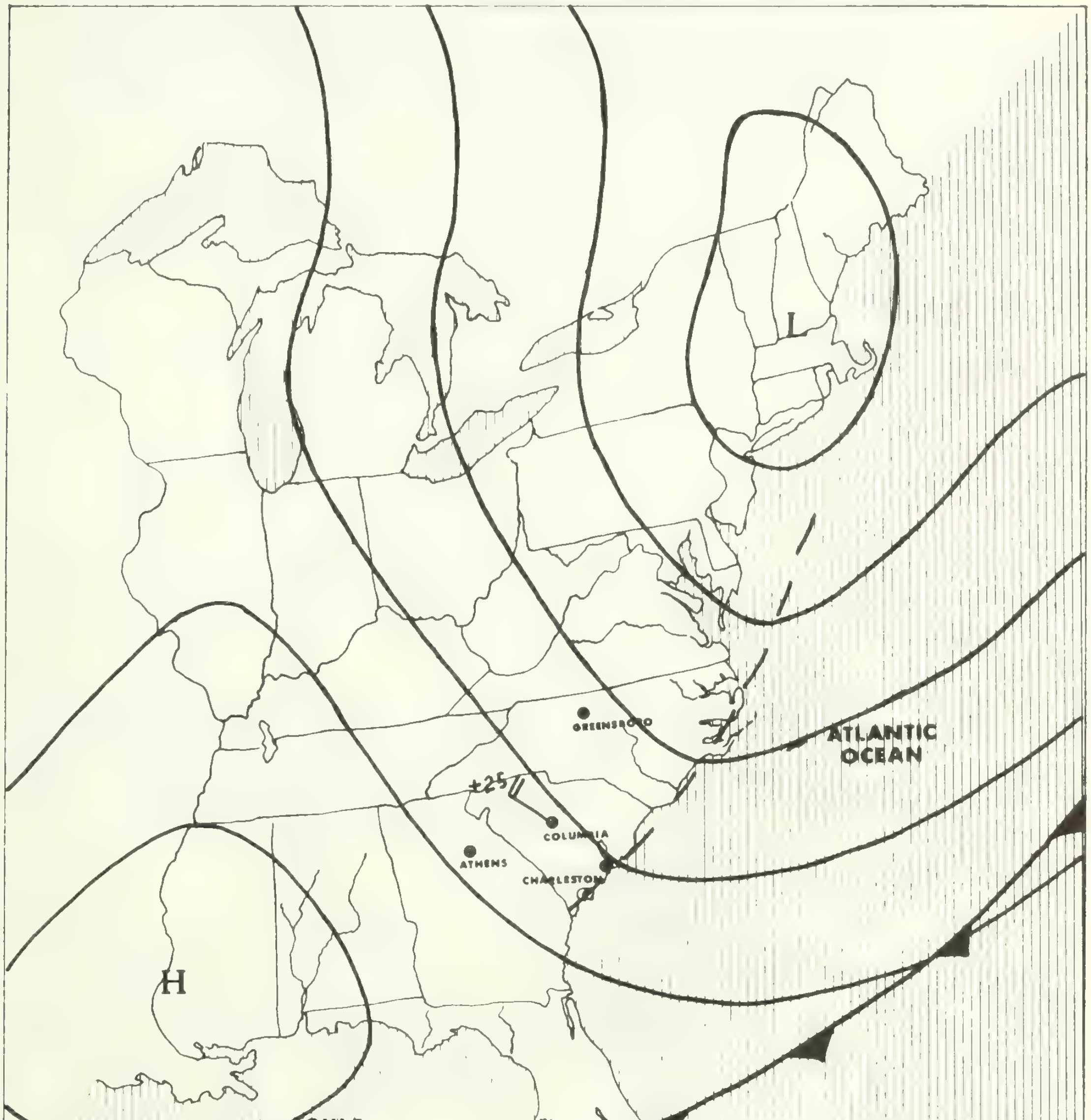


Figure 21.--Surface synoptic features over the eastern United States at 1300 EST on April 2, 1966.

Because of the intervening frontal passage, the 0700 EST Athens sounding was considerably cooler than the one taken at 1900 EST the evening before. The air, however, was still quite unstable in the lower levels. The winds at 0700 EST Saturday morning increased in speed with altitude; by 1300 EST they had decreased in speed aloft, leaving a maximum of 21 m.p.h. between 1,500 and 2,000 feet (fig. 22).

At the fire site, wind observations on the 2nd consisted of two pibal runs, one at 1300 EST, and a second at 1700 EST. The 1300 EST pibal showed a wind maximum of 48 m.p.h. at 1,300 feet and a minimum of less than 20 m.p.h. at 2,100 feet. By 1700 EST, the winds were much weaker and there was no jet point evident (fig. 23).

It is interesting to note that the 1300 EST pibal was taken while the fire was making a major run and that the second pibal was taken just as the fire was lying down near Interstate Highway 26.

The temperature during the second day reached only 65° F., 20° below the maximum of the previous day; and the relative humidity fell to a low of 20 percent, 5 percent below Friday's minimum.

DISCUSSION

During the first afternoon, the fire was wind driven and did not exhibit characteristics of a blowup fire (see footnote 2). The 50 m.p.h. low-level jet was probably too strong to allow the convection column to penetrate to a significant altitude.

The high rate of spread during this period can be attributed to short-distance spotting and to the fact that the winds were of such strength that the flames were often almost horizontally extended. The instability in the lowest few thousand feet of the atmosphere contributed to both of the above phenomena by producing small-scale vertical wind currents and a very gusty wind condition.

That evening, after the passage of the dry, cold front, the fire reached blowup proportions. Because of darkness, it was not possible to determine visually the presence of a convection column; but it is the opinion of the documentation team that the presence of a thunderhead over the fire's head constituted sufficient evidence that considerable vertical development of the convection column had occurred.

Unfortunately, the Fire Documentation Team was not equipped to make nighttime upper wind observations, so no information is available concerning the changes that took place in the winds aloft after the passage of the cold front.

On the second day, the strong winds and low humidities were responsible for the rekindling of the fire just north of Gaston. Once again the soundings at Athens, Greensboro, and Charleston indicated an unstable lapse rate near the ground. This lapse rate, along with local eddies and vortices, contributed to the formation of the fire whirls which carried the fire across the established control lines.

During the fire's major run that afternoon, the fire did manage to develop a limited convection column for short periods of time. However, the strength and gusty nature of the wind caused intermittent fracturing of the column, thereby preventing its full development.

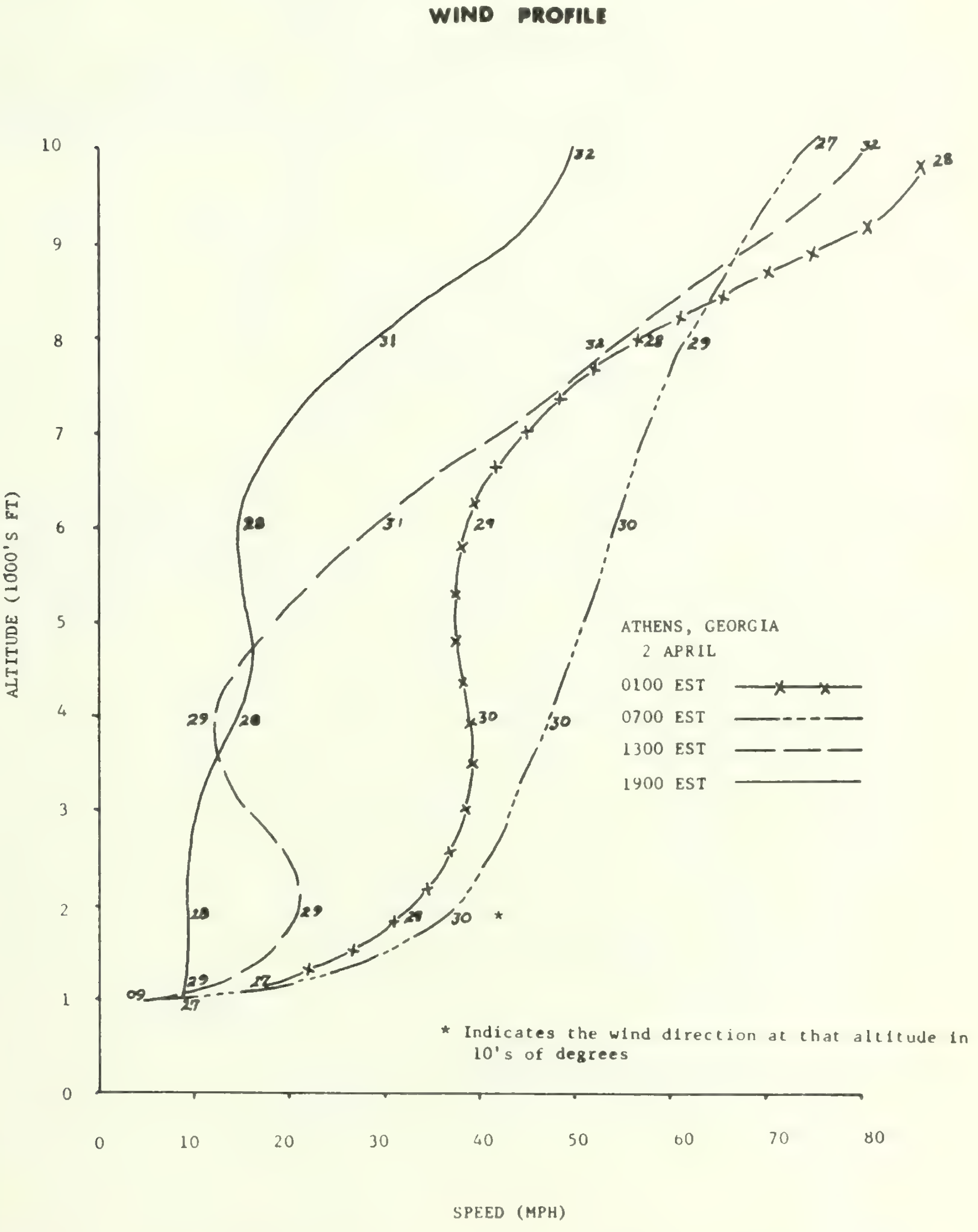
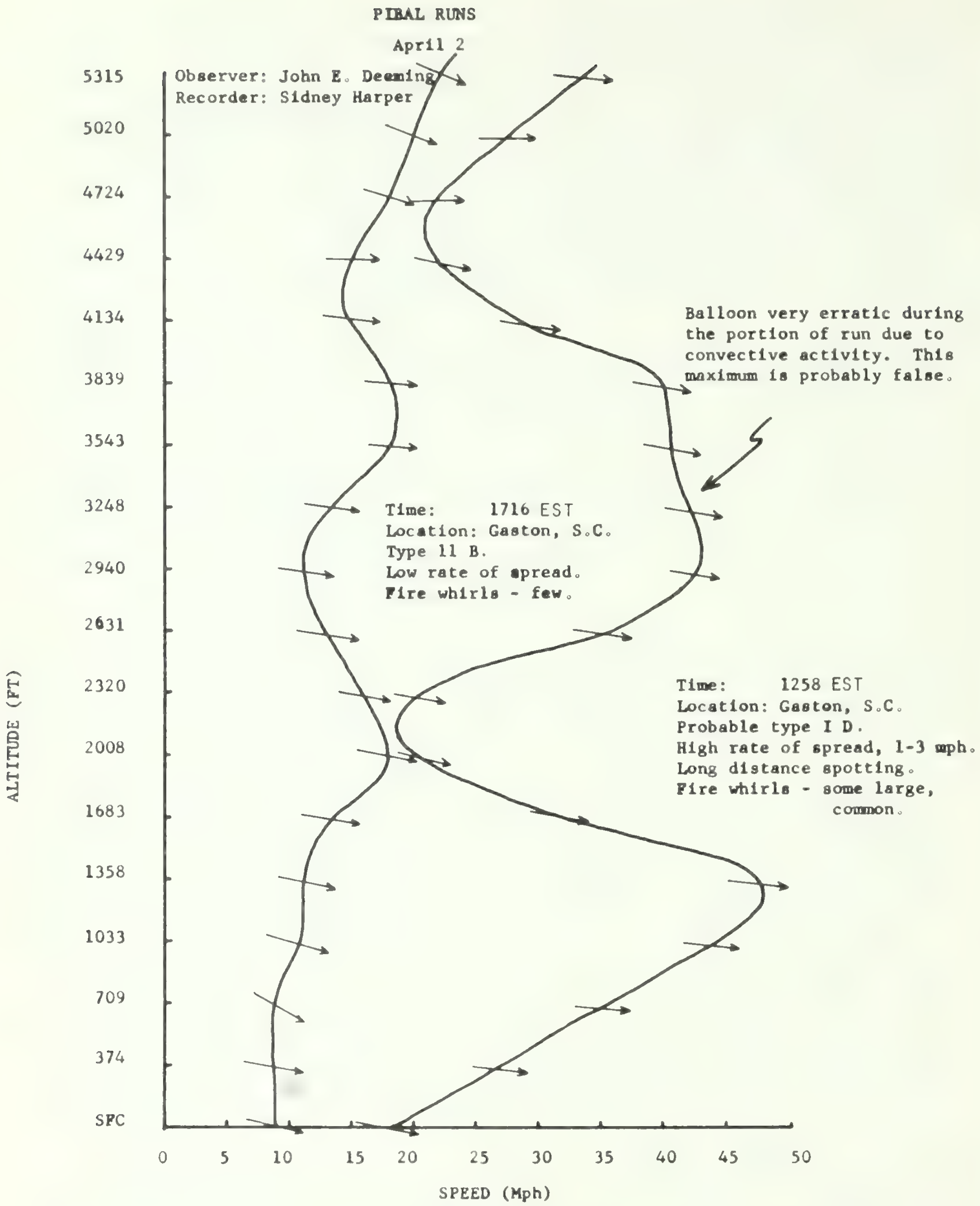


Figure 22.--Wind profiles constructed from raobs taken at Athens, Georgia, on April 2, 1966.



Observer: John E. Deeming
Recorder: Sidney Harper

Balloon very erratic during the portion of run due to convective activity. This maximum is probably false.

Time: 1716 EST
Location: Gaston, S.C.
Type 11 B.
Low rate of spread.
Fire whirls - few.

Time: 1258 EST
Location: Gaston, S.C.
Probable type I D.
High rate of spread, 1-3 mph.
Long distance spotting.
Fire whirls - some large, common.

Figure 23.--Wind profiles constructed from pibal data taken near Gaston on April 2, 1966.

U.S.D.A. Forest Service Research Paper SE-44 February 1969

Some Factors Affecting the Moisture Timelags of Woody Materials

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Southeastern Forest Experiment Station
Asheville, North Carolina

Some Factors Affecting the Moisture Timelags of Woody Materials

by

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Macon, Georgia

The primary theoretical tool available for predicting the effects of weather and fuel variables on the drying rates of forest fuels is the well-known theory of diffusion in solids, which has been developed from the classical theory of heat conduction. The applicability of the theory of diffusion to the drying of forest fuels has not been clearly determined. There is little doubt of the existence of limitations in the classical approach to the drying of solids (3), but some question remains concerning the ways in which these limitations affect the usefulness of the equations. Although actual moisture gradients and moisture content-time curves for woody materials often fail to coincide completely with theoretical curves, relationships between the drying rate constant and variables in the theoretical equations may prove to be correct and useful.

The research reported here was carried out to determine the effects of thickness of the sample, air temperature, and air relative humidity on the drying rate constant, and to compare these experimentally determined relationships with the corresponding theoretical relationships.

Wetting (adsorption) rates were not considered. Under similar conditions, the drying of dead forest fuels should follow the same laws as does the drying of woody materials in the laboratory. Comparison of the experimental results of this study with the corresponding theoretical results, therefore, should be immediately useful in determining the applicability of diffusion theory to drying processes in forest fuels.

ELEMENTS OF CLASSICAL DIFFUSION THEORY

The assumption upon which classical diffusion theory is based is that the rate of mass flow per unit area at any point in an isotropic material is proportional to the concentration gradient of diffusing substance at that point. This statement is known as Fick's first law of diffusion and is stated mathematically as

$$F = -D \frac{\partial C}{\partial x} \tag{1}$$

where F is the rate of mass flow per unit area at a point within the material, $\frac{\partial C}{\partial x}$ is the concentration gradient in the direction of flow at the point, and D is a constant of proportionality usually termed the diffusion coefficient. The minus sign is written to indicate that mass flow is in the direction of decreasing concentration.

Equation (1) may be used to derive Fick's second law of diffusion. This law states that for a given direction of diffusion, the rate of change of concentration of the diffusing substance at any point within the material is proportional to the rate of change of the concentration gradient with respect to distance. For simultaneous diffusion in the x, y, and z directions, the mathematical form of Fick's second law is

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(D\frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(D\frac{\partial C}{\partial z}\right) \tag{2}$$

where C is concentration of diffusing substance and t is time.

To facilitate integration of equation (2), D is usually regarded as constant, so that for the simple case of drying in one direction, say the x direction, equation (2) reduces to

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} \tag{3}$$

It is generally found that D is not constant but a function of either concentration or time, so that solutions of equation (3) are only approximations of the actual drying behavior. Integrations of equation (3) have been carried out for materials of different shapes drying in response to various combinations of initial and boundary conditions. Mathematical descriptions of the diffusion process have been given by Jost (4), Barrer (1), and Crank (2).

The Timelag Concept

In a recent analysis of the drying process in forest fuels, Byram[1] generalized Fick's first and second laws by postulating the existence of a quantity, g, the gradient of which provides the driving force for the diffusion process in forest fuels. He assumed that g is a function of one or more properties of the moisture in the fuel, such as concentration, C, moisture content, m, or vapor pressure, p. Because the nature of the driving force is not known, Byram considered the following expressions for g: C, m, p, CP, and mP, where P is the saturation vapor pressure of water at the drying temperature. In terms of g, Byram's expressions for equations (1), (2), and (3) are

$$F = -k\frac{\partial g}{\partial x} \tag{1a}$$

---

[1] Byram, George M. An analysis of the drying process in forest fuel material. 1963. (Unpublished report on file at the Southern Forest Fire Laboratory, Southeastern Forest Experiment Station, U. S. D. A. Forest Service, Macon, Georgia.)

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left(k\frac{\partial g}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial g}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial g}{\partial z}\right) \tag{2a}$$

$$\frac{\partial C}{\partial t} = k\frac{\partial^2 g}{\partial x^2} \tag{3a}$$

The quantity, k, is interpreted as a moisture conductivity and corresponds to thermal conductivity in heat transfer. The physical meaning and dimensions of k depend on the choice of g. Byram showed that, in a mathematical sense, no single g function is preferable to any other.

In a physical sense, however, certain choices for g seem preferable to others. Byram chose to work with $g = mP$. His analysis of the drying process on this basis shows that the drying of dead forest fuels in the form of rods, slabs, cylinders, cubes, and spheres should be represented by the equation

$$\frac{\overline{m} - m_e}{m_o - m_e} = Ke^{-\left(\frac{N^2kP}{\rho r^2}\right)t} = Ke^{-\left(\frac{N^2D}{r^2}\right)t} \tag{4}$$

except for small values of time. In equation (4)

$\overline{m}$ = average moisture content of the fuel

m_e = equilibrium moisture content

m_o = initial moisture content

K = a dimensionless constant which depends on fuel shape

e = base of Naperian logarithms, 2.718

N = a dimensionless number, the value of which depends on k, r, and the surface moisture transfer coefficient, h

k = fuel moisture conductivity, in sec.

P = saturation vapor pressure of water at the drying temperature, in $\frac{\text{dynes}}{\text{cm.}^2}$

ρ = swollen-volume fuel density, in $\frac{\text{gm.}}{\text{cm.}^3}$

r = half-thickness or radius of the fuel, in cm.

t = time, in sec.

D = diffusion coefficient (or moisture diffusivity) of the fuel, in $\frac{\text{cm.}^2}{\text{sec.}}$

All moisture contents are expressed as fractions of the ovendry weight of the fuel. Equation (4) is a solution of equation (3a) and is based on several assumptions: (a) the fuel is an isotropic, nonshrinking material; (b) moisture conductivity, k, and diffusion coefficient, D, are constants in any single drying process; (c) a uniform distribution of moisture exists in the fuel prior to drying; (d) diffusion occurs only in the r direction; (e) temperature gradients do not exist in the fuel during drying; (f) fuel temperature is the same as ambient air temperature; and (g) evaporation of moisture occurs only at the fuel surface. Although few of these assumptions are valid for actual drying processes, equation (4) may be a sufficiently good description of the drying process to predict correctly how the variables involved affect the drying rate.

The timelag "constant," or timelag, is a parameter which is characteristic of all physical and chemical processes that occur at an exponentially decreasing rate. When written in terms of the timelag, τ, equation (4) becomes

$$\frac{\overline{m} - m_e}{m_o - m_e} = E = Ke^{-\frac{t}{\tau}} \tag{5}$$

where

$$\tau = \frac{\rho r^2}{N^2 kP} = \frac{r^2}{N^2 D} \tag{6}$$

and E is the fraction of total evaporable moisture remaining in the fuel at time t. A plot of E versus time on semilogarithmic graph paper will be linear if equation (5) is obeyed. The slope of such a plot, derived from differentiation of the logarithmic form of equation (5), is

$$\frac{d}{dt}(\ln E) = -\frac{1}{\tau} \tag{7}$$

The constant K is the value of E at which the extended linear portion of the plot (extrapolated to $t = 0$) intersects the E-axis, and its theoretical value depends only on the shape of the drying fuel. From experimentation, on the other hand, it is found that K is not determined solely by the shape of the fuel; other unknown factors affect its magnitude. The countless combinations of fuels and drying conditions found in the forest make evaluation of K for each fuel and drying condition an impossible task. However, experimental values of K for uniform samples are usually close to unity. For this reason the timelag concept, as applied to the drying of forest fuels, is based on the assumption that $K = 1$. On this basis, the moisture timelag is defined as the time required for the difference between the average and equilibrium moisture contents, $(\overline{m} - m_e)$, to decrease to the value $\frac{1}{e}(m_o - m_e)$ under constant drying conditions. Thus, when $t = \tau$ in equation (5), the fraction of evaporable moisture remaining in the fuel is $\frac{1}{e}$, or 0.368.

The timelag cannot be calculated directly from equation (6) because values of N^2, k, and D are not known. However, the timelag may be determined experimentally by application of equation (7) to a semilogarithmic plot of the drying data in which E is shown as a function of t. An alternative method of determining τ from the same plot is to draw a line through the point $E = 1$, $t = 0$, with a slope parallel to the linear portion of the curve; timelag τ is the value of t for which $E = 0.368$. Construction of a line parallel to the linear portion of the data and passing through the given point is necessary in order to graphically correct K to a value of unity.

Relationships Between the Timelag and Certain Drying Variables

Among the many factors which influence the drying of forest fuels are fuel thickness, air temperature, fuel density, relative humidity, windspeed, and initial moisture content. Relationships between the timelag and some of these factors may be predicted theoretically by means of equation (6). For example, the timelag should be proportional to r^2, according to equation (6). Byram (see footnote 1) has shown that this type of behavior is to be expected when r is large and the rate of moisture loss is limited by the rate of internal moisture flow, that is, by the internal resistance. Under these conditions, N^2 approaches the value $\frac{\pi^2}{4}$. However, when r is small, the rate of moisture loss is determined primarily by the surface resistance. In this case, N^2 in equation (6) approaches the value $\frac{hr}{k}$, where h is the coefficient of moisture transfer at the fuel surface. Drying under these conditions occurs with a relatively small moisture gradient through the fuel, and the timelag in equation (6) becomes

$$\tau = \frac{\rho r^2}{N^2 k P} = \left(\frac{k}{hr}\right) \left(\frac{\rho r^2}{kP}\right) = \frac{\rho r}{hP} \qquad (8)$$

Thus, diffusion theory predicts that a log-log plot of τ against r for constant-density fuels of varying thicknesses which are drying in constant-temperature surroundings should have a slope of 2.0 except when r has very small values, in which case a slope of unity should be approached.

The effect of air temperature on τ is evident from its effect on the saturation vapor pressure of water, P. According to equation (6), a log-log plot of τ against $\frac{1}{P}$ should have a slope of unity for fuels of equal thickness and density which are drying in surroundings of different temperatures.

The effect of fuel density on the timelag should result in a log-log plot of τ against ρ with a slope of unity, according to equation (6).

Variables such as relative humidity, windspeed, and initial moisture content do not appear in equations (6) and (8). Thus, from the standpoint of the theory upon which the equations are based, these variables have no effect on the magnitude of the timelag.

EXPERIMENTAL PROCEDURE

The purpose of the experimental work was (1) to determine the effects of thickness of the sample, air temperature, and air relative humidity on the timelag constants of several types of woody materials and (2) to compare these effects with the corresponding effects predicted from diffusion theory in the previous section. Study of the effects of sample density and windspeed was omitted. The effect of initial moisture content on the magnitude of the timelag was studied briefly with one of the experimental materials, but was not of major interest.

Drying measurements were made on layers of white fir, Abies concolor (Gord. and Glend.) Lindl., sawdust which had a swollen-volume bulk density of about 0.10 gm./cm.^{3}, on square rods sawn from white fir lumber which had a density of 0.350 gm./cm.^{3}, and on slabs built up from individual sheets of thin copy paper which had a density of 1.0 gm./cm.^{3}. Most of the samples were dried from an initial moisture content of approximately 100 percent so that the effect of a high initial moisture content on the shapes of the moisture content-time curves could be studied. All measurements were made inside a walk-in cabinet in which dry bulb temperatures and relative humidity were controlled. The average range of variation of the dry and wet bulb temperatures was about 4° F.; the maximum observed variation was 5.7° F. These temperature variations caused a maximum oscillation in relative humidity of about ± 5 percent from the mean values. The sawdust layers were dried in aluminum pans; the square wooden rods and paper slabs were dried on hardware cloth supported above a table so that air could circulate freely on all sides. Weight loss measurements were accurate to ± 0.5 percent. When the moisture content of each sample had reached equilibrium with conditions in the cabinet, the sample was ovendried at 105° C. and its ovendry weight determined.

The effect of thickness on the timelags of samples of sawdust, wood, and paper, each held at approximately 81° F. and 36 percent relative humidity, was studied. Determinations on the sawdust were made on layers which were of the following four wet thicknesses--0.9, 1.5, 2.8, and 5.5 centimeters. Samples at each thickness were dried from initial moisture contents of 104, 58, and 34 percent. All layers were dried in a constant wind of 2.2 m.p.h. (These samples were dried before wind was omitted as an experimental variable.)

The effect of thickness on the timelags of the wooden rods was evaluated under conditions in which the movement of air was caused only by circulation in the humidity cabinet itself--conditions approaching free convection. Rods of the following thicknesses, based on air-dry thickness at 11 percent moisture content, were tested: 0.14, .33, .64, 1.3, and 2.6 centimeters. The rods were dried from initial moisture contents near 100 percent.

The effect of thickness on the timelags of the paper slabs was measured under conditions similar to those used for the square rods. The wet slabs were approximately 0.013, .025, .051, .102, and .203 centimeter thick. Measured values of initial and equilibrium moisture contents are in slight error because of decomposition of the paper during ovendrying. However, the weight loss-time data are accurate because they did not depend on determination of the starting and final moisture content values.

The effect of temperature on the timelag was evaluated for four layers of sawdust 0.80 centimeter thick and for four square wooden rods 0.64 centimeter thick. Tests were run at temperatures of 60, 80, 90, and 100° F., with the samples initially in thermal equilibrium at the test temperatures. Relative humidity was held at about 39 percent, and all samples were dried in free-convection surroundings. The initial moisture content of the sawdust samples averaged 92 percent with variations of only 3 percent. The wood samples, however, varied from 55 to 88 percent in initial moisture content because of moisture loss during storage at the test temperature. This loss may have resulted from an evaporation-condensation process caused by small air temperature fluctuations within the storage cabinet.

The effect of relative humidity on the timelag of four layers of sawdust 0.80 centimeter thick and five 1.27-centimeter square wooden rods, each held at a temperature of about 80° F., was studied. Relative humidity values for drying of the four sawdust layers were 69, 50, 36, and 21 percent; corresponding values for the five wooden rods were 83, 60, 46, 30, and 18 percent. Samples within each fuel type were of nearly equal densities and were dried under free-convection conditions. Initial moisture contents of both the sawdust and wood averaged 93 percent.

EXPERIMENTAL RESULTS

The weight-time data for all samples were plotted on semilogarithmic graph paper so that timelags could be determined in accordance with equation (7). Even for large times, the experimental curves did not take the general form predicted by equation (5), although certain portions of the curves were linear in accordance with the theory (fig. 1). In most cases, the semilogarithmic plots could be separated into three distinct regions. The region corresponding to the smallest times was linear; this portion of the curve usually began at the point at which drying started and ended at a point which represented a moisture change between 30 and 80 percent of the total change. The second portion of the curve was curvilinear, extending from the point at which the initial linear portion stopped to a point at which the sample had lost 80 to 90 percent of its evaporable water. The third region of the curves was usually linear, but with a slope different from that of the first region. Because most of the samples gave semilogarithmic plots with two linear regions, they were considered to exhibit two timelags. Thus, the effects of thickness, air temperature, and relative humidity were evaluated for two timelags, τ_1 and τ_2. The symbol τ_1 refers to the linear region associated with the initial stage of drying; the symbol τ_2 refers to the linear region associated with the final stage of drying.

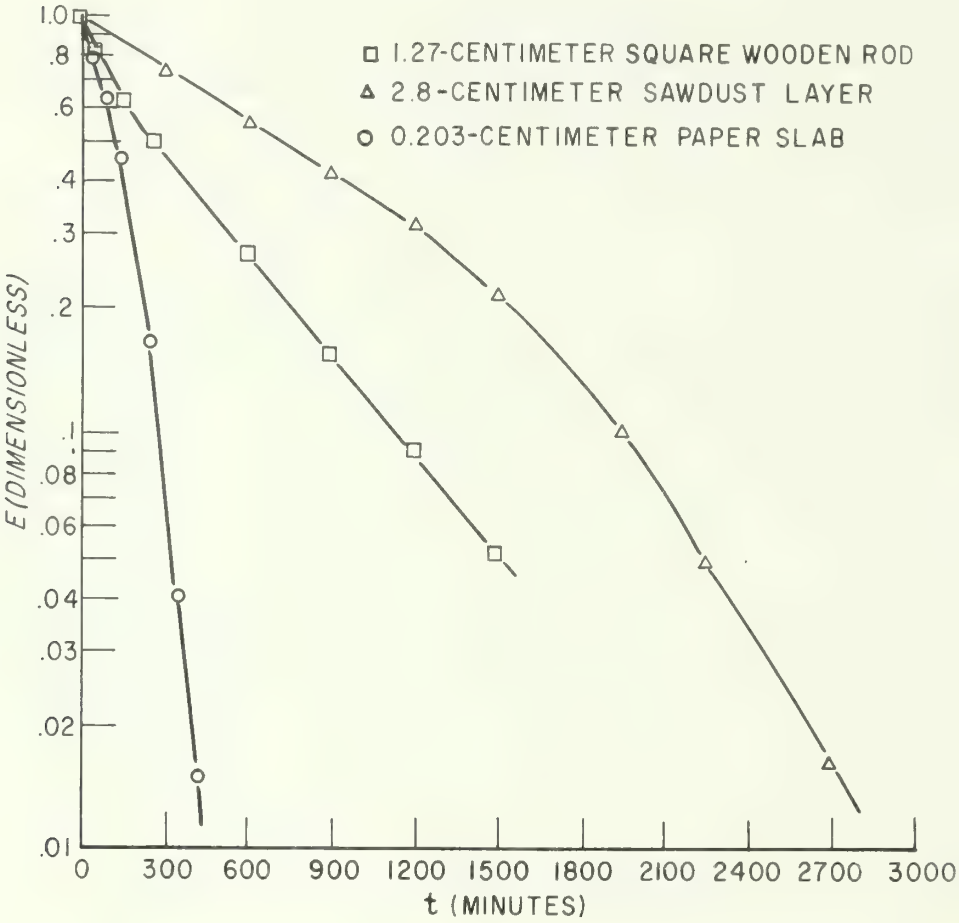

Figure 1.--Typical drying curves for sawdust layers, square wooden rods, and paper slabs dried at 81° F. and 36 percent relative humidity. The fraction of total evaporable moisture in the sample, E, is plotted against time.

The Effect of Thickness

The effects of thickness on τ_1 and τ_2 for the three types of samples are shown in figures 2, 3, and 4. For sawdust (fig. 2), τ_1 is dependent on initial moisture content and thickness, whereas τ_2 is dependent only on thickness, provided that the initial moisture content exceeds 34 percent. The 34-percent samples exhibited only one timelag because of their low initial moisture contents. The slopes of the plots for both τ_1 and τ_2 are 1.85. Although this value is slightly smaller than the theoretical value of 2.0, it agrees well with the value of 1.80 found by Byram (see footnote 1) for similar drying experiments with sawdust. The reason for this slight deviation from theory is not clear.

Figure 3 shows τ_1 and τ_2 plotted against r for drying of the square wooden rods. Initial moisture contents of all samples but the 2.56-centimeter rod were close to 100 percent; its initial moisture content was 73 percent and was not uniformly distributed. The slope of the line is 2.0, which is in agreement with the theoretical value.

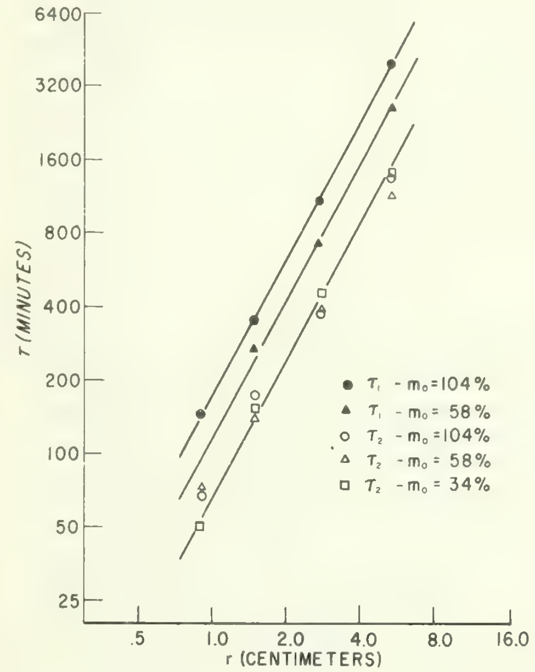

Figure 2.--The effect of thickness on timelags τ_1 and τ_2 of sawdust layers dried at 81° F. and 36 percent relative humidity. The layers were dried from three different initial moisture contents to equilibrium moisture contents of about 10 percent.

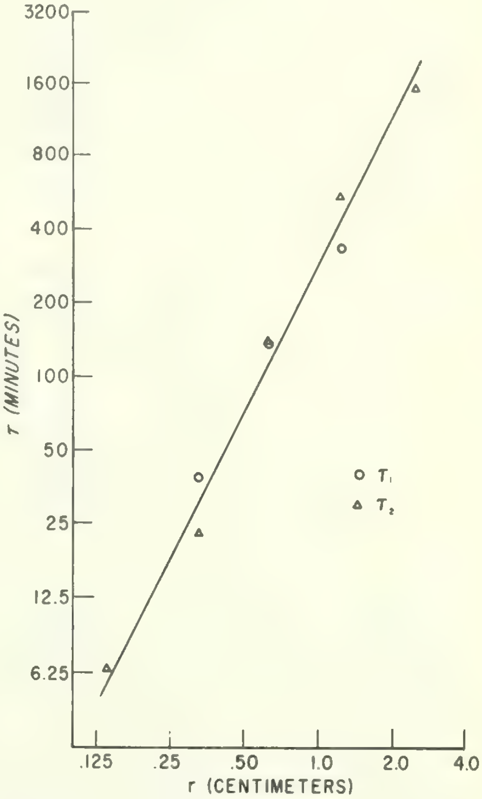

Figure 3.--The effect of thickness on timelags τ_1 and τ_2 of square wooden rods dried at 81° F. and 36 percent relative humidity. The rods were dried from approximately 100 percent moisture content to equilibrium moisture contents of about 10 percent.

The effect of thickness on the timelags of the paper slabs is shown in figure 4. As r increases, the τ_1 - r curve reaches a slope of 1.27, whereas the τ_2 - r curve reaches a slope of 2.0. According to diffusion theory, the τ_1 - r curve should apply when resistance to moisture transfer from the sample surface is large compared with the resistance to internal moisture transfer. In this case, τ_1 should be linear against r with a slope of unity.

Both timelags τ_1 and τ_2 show a tendency to become independent of thickness at values of r in the neighborhood of 0.02 centimeter. However, this observation is based on very limited data near the end of the curves in figure 4. Theoretically, the timelag cannot become independent of thickness. On the other hand, mass drying rates (grams of water lost per unit time) can demonstrate this behavior if the drying process becomes independent of the sample properties. The data for small r values suggested that a mechanism other than diffusion may have been controlling the drying process in the two thinnest samples. Therefore, mass drying rates were calculated for the samples and plotted as functions of the variable E. The drying rates for both samples were nearly equal at equal values of E during the entire drying process and were constant during the first half of the total change in moisture content. Thus, constant-rate drying occurred, indicating that the rate of drying depended upon external conditions rather than upon physical properties of the samples. According to Hougen et al. (3), drying of paper pulp from moisture contents above the fiber saturation point results from capillarity rather than diffusion.

The Effect of Temperature

A dimensionless plot of the timelags τ_1 and τ_2 against the reciprocal of the saturation vapor pressure, $\frac{1}{P}$, is given for both the sawdust layers and the square wooden rods in figure 5. The measured τ_1 values for the wood samples were scattered--probably because of variability in their initial moisture contents. Therefore, on the assumption that timelag τ_1 varies directly as $(m_o - m_e)^{\frac{1}{2}}$, a correction of these measured values to a constant initial moisture content of 55 percent was made (see dashed curve in fig. 5). This assumption is based on the meager data in figure 2 and should be verified with more extensive tests. The values shown for sawdust (fig. 5) are actual values; they resulted in a curved line, similar to the curve for corrected values of the wood samples, indicating that the effect of temperature on τ_1 at temperatures near 100° F. may not be in accordance with theoretical predictions. Preliminary temperature measurements on sawdust layers of 100 percent moisture content which were drying at 80° F. and about 30 percent relative humidity indicate that the temperature within the layer drops about 10° F. during the early stages of drying. Increased significance of this cooling effect at temperatures of 90° and 100° F. could account for curvilinearity in the data, but such is not known definitely to be the case. The τ_2 values for both wood and sawdust lie on a straight line with a slope of unity. (Two of the values for wood were not obtainable because of nonlinearity of the data during the late stages of drying.) The results indicate close agreement between the theoretical and experimental relationships in the temperature range from 60° to 100° F.

Similar results have been observed by Stamm and Wilkinson (6). They found that, for temperatures up to about 100° C., the diffusion coefficients for fiberboard which was dried from near the fiber saturation point increased with temperature in proportion to the saturation vapor pressure of water.

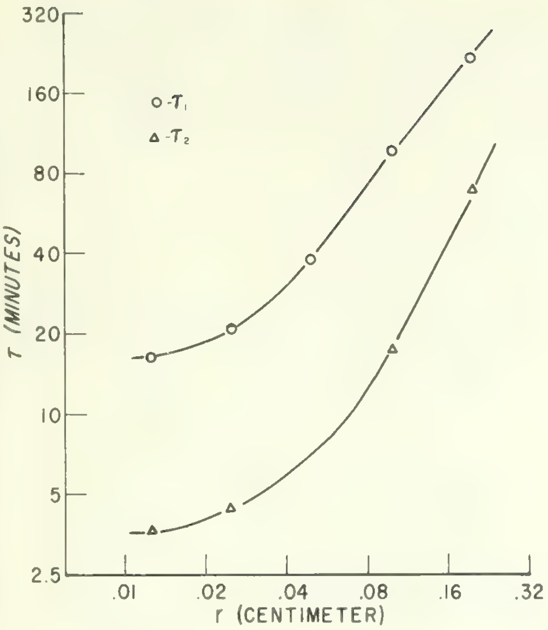

Figure 4.--The effect of thickness on timelags τ_1 and τ_2 of paper slabs dried at 81° F. and 36 percent relative humidity. The slabs were dried from moisture contents in the neighborhood of 130 percent to equilibrium moisture contents of about 10 percent. Initial and equilibrium moisture contents are approximate because of slight decomposition during ovendrying. (The τ_2 value at r = 0.051 centimeter is missing because the watch stopped during the measurements.)

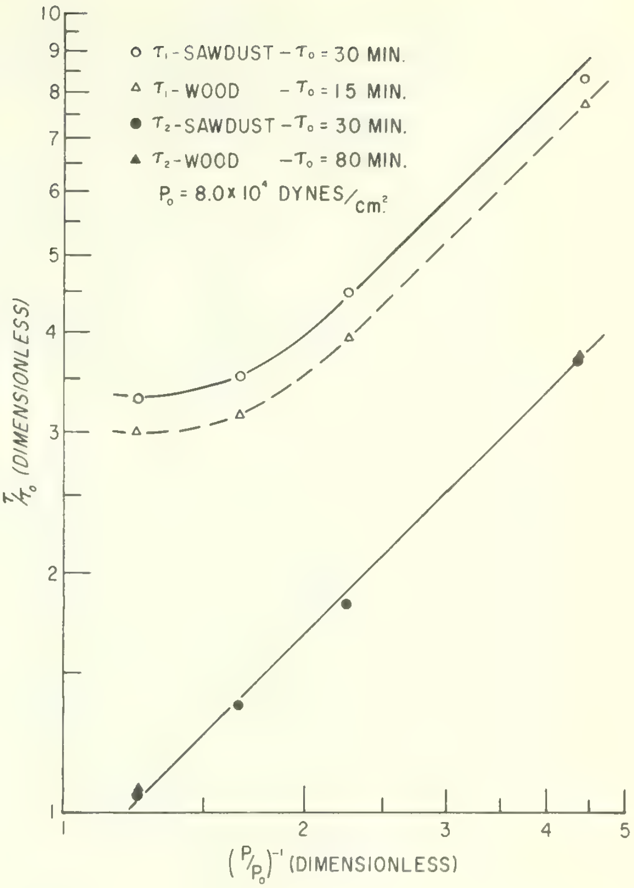

Figure 5.--The effect of temperature on the timelags τ_1 and τ_2 of sawdust layers 0.80 centimeter thick and wooden rods 0.64 centimeter square. The samples were dried at a relative humidity of 39 percent to equilibrium moisture contents of about 10 percent. The initial moisture content of the sawdust layers was 92 percent, and that of the wooden rods was 55 percent. Temperatures ranged from 60° to 100° F. (The terms τ_0 and P_0 are convenient constants which were used so that all curves could be shown on one graph.)

The Effect of Relative Humidity

In experiments on the effect of relative humidity, timelags τ_1 and τ_2 were observed for all sawdust samples but for only three of the wood samples. Several trial plots were made of the experimental timelags as functions of relative humidity. Both τ_1 and τ_2 were best correlated with relative humidity by the equation

$$\tau = C\left(\frac{100}{100 - H}\right) \tag{9}$$

where H is relative humidity in percent and C, a constant with dimensions of time, represents the value of τ when H = 0. A log-log plot of the experimental data is shown in figure 6. The slope of each line is unity. Thus, the data indicate that the timelag is not independent of relative humidity as predicted by equation (6). Further investigation of the effect of relative humidity on the timelag of a number of fuels is needed to verify and extend the data in figure 6.

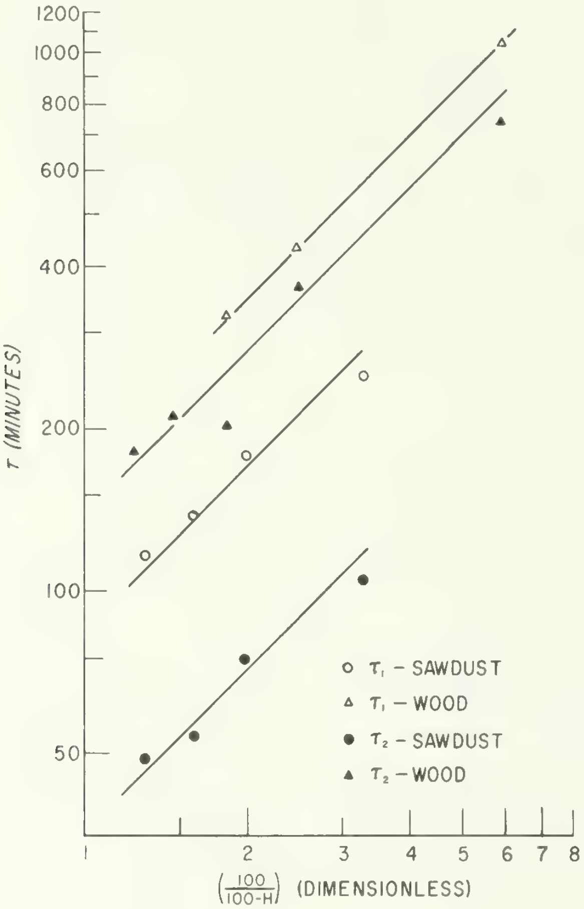

Figure 6.--The effect of relative humidity on the timelags of sawdust layers 0.8 centimeter thick and wooden rods 1.27 centimeters square. The samples were dried at 80° F. from initial moisture contents of about 93 percent.

Knowledge of the effect of relative humidity on the timelag is important from a practical standpoint because development of the National Fire Danger Rating System requires a method of correcting drying rates to standard drying conditions of 80° F. and 20 percent relative humidity. The method of correction was developed by Byram (see footnote 1), who used the assumption that drying of forest fuels occurs in response to a vapor pressure gradient within the fuel. He derived the drying rate ratio, R, for correcting a drying rate observed at temperature T′ and relative humidity H′ to standard temperature T and standard relative humidity H.

According to Byram, the drying rate ratio for fuels drying from initial moisture contents of at least 20 percent may be calculated approximately from the equation

$$R = \frac{\frac{dM}{dt}}{\frac{dM'}{dt}} = \frac{(100 - H)P}{(100 - H')P'} \qquad (10)$$

where P' and P are saturation vapor pressures of water at temperatures T' and T, and $\frac{dM'}{dt}$ and $\frac{dM}{dt}$ are mass drying rates evaluated when $t = \tau'$ and $t = \tau$.

The experimental results indicate that an equation similar to equation (10) may be used to correct any observed timelag τ' to a value τ which corresponds to standard drying conditions. We define a timelag ratio R_τ as the ratio of the timelag for a fuel drying under standard conditions to the timelag for the same fuel drying under conditions other than standard. If temperature and relative humidity are considered to be the only environmental variables affecting the timelag, then the empirical relationships in figure 5 and figure 6 may be combined into a single expression which gives the effects of temperature and relative humidity on the timelag. From figure 5, we have the relation (for temperatures below about 95° F.)

$$\tau \propto \frac{1}{P}$$

and from figure 6, the effect of relative humidity on the timelag is

$$\tau \propto \left(\frac{100}{100 - H}\right)$$

We can combine these two expressions into

$$\tau \propto \left(\frac{100}{100 - H}\right)\frac{1}{P}$$

which may be rewritten as

$$\tau = A\left(\frac{100}{100 - H}\right)\frac{1}{P}$$

where A is a constant. If this equation is valid for all values of H and P normally present in the forest, then the timelag of a fuel drying under conditions which differ from standard conditions is related to the timelag for standard conditions by the timelag ratio

$$R_\tau = \frac{\tau}{\tau'} = \frac{(100 - H')P'}{(100 - H)P} \qquad (11)$$

where primed quantities refer to actual drying conditions and unprimed quantities refer to standard conditions. Equations (10) and (11) show that the timelag ratio, R_τ, is the reciprocal of Byram's drying rate ratio, R.

DISCUSSION OF RESULTS

The experimental results indicate that woody materials with initial moisture contents greater than the fiber saturation point often dry in two or more stages, with different timelag constants associated with each stage. The appearance of two drying stages may not be of great significance from a practical standpoint because much more moisture is usually lost during the first stage than during the second stage. However, evidence of a more serious limitation is given in figure 2, in which the magnitude of the timelag appears to depend on initial moisture content of the drying material. The practical significance of this effect is not clear. In the field, the effect may be reduced considerably by the presence of other variables, such as solar radiation, wind movement, and nonuniformity of fuel. On the other hand, under certain environmental conditions the timelags of actual fuels may be affected to about the same extent as were the timelags of the sawdust layers depicted in figure 2. If so, the effect is of considerable importance. For example, if the timelag of a 2-inch layer of fuel material is measured experimentally at a moisture content of 34 percent and if drying of the layer occurs after a rain which has raised the fuel moisture to about 60 percent, then, according to figure 2, use of the measured 34-percent value for the timelag at 60-percent moisture will result in an error of about 43 percent.

The effect of initial moisture content should be most significant during early stages of drying when the materials contain considerable free water. The controlling mechanism during these stages may be either moisture diffusion, heat diffusion, capillarity, or some combination of these factors; its appearance is probably determined by initial moisture content, thickness and nature of the material, and the drying conditions. In the later stages of drying, when much of the free water has been lost, or for initial moisture contents below the fiber saturation point, the controlling mechanism is probably a combination of bound water and water vapor diffusion, as is discussed for the case of wood drying by Stamm and Nelson (5). The relative proportion of each type of diffusion is determined primarily by the internal structure of the material.

CONCLUSIONS

Diffusion theory, in spite of limitations in its description of drying processes in woody materials, is useful for predicting the effects of certain fuel and weather variables on timelag constants of sawdust layers, square wooden rods, and paper slabs. The drying of these materials from moisture contents of 60 percent or greater often occurs in two or more stages, with the occurrence of more than one stage apparently depending on the initial moisture content and the thickness of the drying material.

Theoretical relationships between the timelag and the variables studied are generally applicable to both the initial and final stages of drying even though different timelags are usually associated with each stage, and it is questionable whether simple moisture diffusion occurs during the initial drying stage.

Final-stage timelags of the experimental materials discussed in this report are approximately proportional to the square of sample thickness, provided this thickness exceeds 0.9 centimeter for sawdust layers, 0.14 centimeter for square wooden rods, and 0.10 centimeter for paper slabs. Initial-stage timelags of sawdust and wood are affected by sample thickness in the same way; however, in paper slabs less than 0.2 centimeter thick, the observed initial timelag becomes approximately proportional to the first power of thickness, as predicted for thin materials by diffusion theory. Thus, diffusion theory provides considerable insight into drying processes in thin materials. In extremely thin materials, such as single and double sheets of paper, the drying process is not controlled by diffusion; and the mass drying rates become independent of thickness.

The effect of temperature on the final-stage timelags of wood and sawdust can be predicted by diffusion theory in the temperature range from 60° to 100° F. These timelags are inversely proportional to the saturation vapor pressure of water at the drying temperature. A similar temperature effect occurs for initial-stage timelags up to a temperature of at least 90° F.

The effect of relative humidity on the timelags of the experimental materials in this study was not correctly predicted by the diffusion theory. For sawdust layers and wooden rods, the timelag observed for drying in percent relative humidity H is proportional to the quantity $\left(\frac{100}{100 - H}\right)$.

As this work has shown that the drying process in woody materials may consist of two or more stages, there is now a need to know the range of fuel and weather variables for the different stages and to determine their significance in fire danger measurement. Another research need is study of the effects of size, density, and initial moisture content on timelags of materials dried in atmospheres of oscillating temperature and relative humidity. Research on these two problems should be helpful in successful application of the timelag concept to moisture changes in forest fuels.

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Regional Variation in Specific Gravity of Seven Pines in the Southern United States

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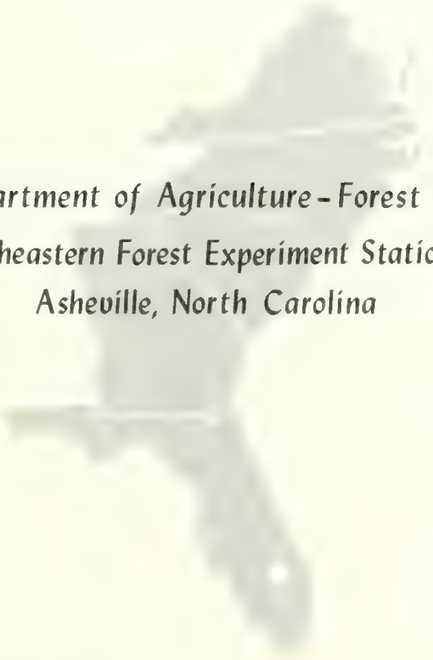

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Regional Variation in Specific Gravity of Seven Pines in the Southern United States

by

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Tree improvement programs are an important part of forest management. In such programs, large numbers of trees are examined for tree and wood characteristics in order to establish standards for each characteristic. An important feature of this work is that above-average trees are located and retained for propagation and breeding purposes.

Region 8 of the U. S. Forest Service has been conducting a tree improvement program since 1961. Trees are first selected on the basis of external characteristics and are then further examined for wood density. In the course of this selection program, over 7,500 trees of seven different pine species were evaluated for specific gravity.

The objective of this study was to examine these data for geographic variation in specific gravity throughout the southern part of the United States. Such information is useful to wood purchasers with certain product requirements, to forest managers who wish to exert some control on the quality of wood they produce, and to those interested in tree improvement through selection and breeding.

Larson (1957) was the first to show that there is an increase in the percentage of summerwood, and therefore in specific gravity, in slash pine trees from north to south and from west to east within the natural range of the species. These observations were confirmed by Perry and Wu (1958) and by Goddard and Strickland (1962). Zobel et al. (1960) reported similar trends for loblolly pine in the southeast. Mitchell and Wheeler (1959) reported that specific gravity values for loblolly and shortleaf pines increase from north to south in Mississippi. In a later report from these data, Wheeler and Mitchell (1962) presented isograms showing that, for both species, specific gravity values increase from the northwest to the southeast corners of the state. The report also includes specific gravity zones for longleaf and slash pine in southeastern Mississippi. Mitchell (1964), reviewing his past work, also developed isograms for loblolly pine in the southeastern states. In these isograms, specific gravity values increase from 0.48 in north Alabama and Georgia to 0.58 in central Florida.

In a report on wood density of the four major southern pine species, the Forest Products Laboratory (U.S.D.A. Forest Service 1965) presented specific gravity data which were gathered in Arkansas, Louisiana, Mississippi, Alabama, Georgia, Florida, and North Carolina. Although the data from some locations were insufficient for a thorough evaluation of geographic trends, the report did confirm the fact that specific gravity values over this broad area increased from north to south and from west to east. These trends were not nearly as distinct as they had appeared in previous studies, however; and, in the case of shortleaf and loblolly pines, the west-to-east trend was very weak or nonexistent.

MATERIALS AND METHODS

The sample locations for this study were National Forest areas located in Region 8 of the U. S. Forest Service (fig. 1). The species examined were loblolly pine (Pinus taeda L.), longleaf pine (Pinus palustris Mill.), shortleaf pine (Pinus echinata Mill.), slash pine (Pinus elliottii Engelm.), sand pine (Pinus clausa [Chapm.] Vasey), Virginia pine (Pinus virginiana Mill.), and eastern white pine (Pinus strobus L.).

In the Region 8 screening program, trees with outstanding phenotypic characteristics, such as rate of growth, straightness, crown size, branch size, and angle, were selected by Forest Rangers. These trees were later graded by Region 8 staff members, and those classified as superior tree candidates were sampled for wood characteristics by removing two standard size increment cores (0.177 to 0.200 inch in diameter) from diametrically opposite sides of the tree at breast height. Five other trees in the vicinity of each superior tree candidate were sampled in the same manner and served as comparison trees. Both the superior tree candidates and the comparison trees were used in this study after t-tests indicated no significant difference in specific gravity between the groups (table 1).

In the laboratory, the two cores from each tree were checked for compression wood, pitch soak, and other defects. The more defective of the two cores was discarded, and the better core was used in determining the tree's specific gravity. This determination, which was made by the maximum moisture method outlined by Smith (1954), was based on the green volume and ovendry weight of the core. All cores contained the natural extractives at the time of the determination.[1]

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[1] Extractives in increment cores can result in a 6.0 to 7.5 percent overestimate of wood substance. Anyone interested in the specific gravity values of these samples if they were extractive-free can compute them by using regression equations developed by Taras and Saucier (1967) for the four major southern pine species. These regression equations were developed from material collected for this study.

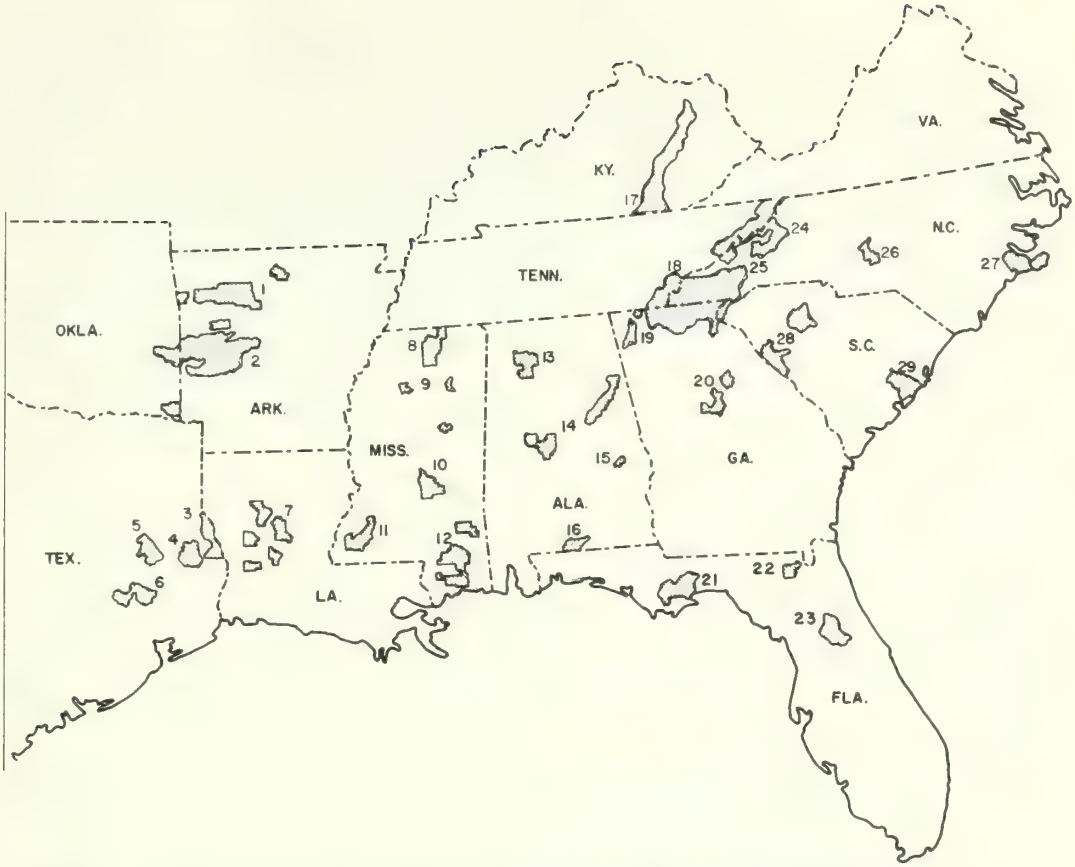

Figure 1.--The following National Forests in Region 8 were sampled in this study: (1) Ozark, (2) Ouachita, (3) Sabine, (4) Angelina, (5) Davy Crockett, (6) Sam Houston, (7) Kisatchie, (8) Holly Springs, (9) Tombigbee, (10) Bienville, (11) Homochitto, (12) DeSoto, (13) Bankhead, (14) Talladega, (15) Tuskegee, (16) Conecuh, (17) Daniel Boone, (18) Cherokee, (19) Chattahoochee, (20) Oconee, (21) Apalachicola, (22) Osceola, (23) Ocala, (24) Pisgah, (25) Nantahala, (26) Uwharrie, (27) Croatan, (28) Sumter, (29) Francis Marion.

Table 1.--Mean specific gravity of superior trees and comparison trees and tests of significance

Pine species	Paired samples	Mean specific gravity		"t" values*
		Superior trees	Comparison trees	
	Number			
Loblolly	559	.508	.509	.01
Longleaf	617	.567	.575	.15
Sand	58	.490	.476	.24
Shortleaf	695	.514	.520	.09
Slash	277	.532	.535	.05
Virginia	89	.502	.496	.10
White	185	.341	.359	.31

*$t_{.01}$ = 2.66 when n = 60.
$t_{.01}$ = 2.58 when n = ∞.

RESULTS AND DISCUSSION

The number of trees collected and their mean age, d.b.h., and specific gravity values are presented by species in table 2. Further breakdown of the data by National Forests and by states is presented in tables 3 and 4 of the appendix. Mean age and d.b.h. are included in these tables because these parameters are associated with specific gravity and should be considered when comparisons between species or between locations within species are being made. Of the two parameters, age is of greater importance in its relation to specific gravity. The rate of change in specific gravity with age is rapid in young trees but levels off at about age 15 in southern pines. In this study only trees producing mature wood were sampled, and the age-specific gravity relationship in these older trees should be less important. This is indicated by the low, but significant, correlation values of r = 0.20, 0.15, 0.25, and 0.22 for loblolly, longleaf, shortleaf, and slash, respectively. The d.b.h.-specific gravity correlations were even lower in all cases, and not significant. Knowledge of the range of variation in specific gravity that occurs within and between locations is a first requirement for tree breeding, and these data are included in all tables. The National Forest data are also illustrated in figures 2 through 4 for the major southern pine species.

Table 2.--Specific gravity by species

Pine species	Sample trees	Mean age	Mean d.b.h.	Specific gravity		
				Range	Mean	Standard deviation
	Number	Years	Inches			
Loblolly	1,742	47	14.8	.38 to .68	.51	.036
Longleaf	1,576	50	11.7	.40 to .75	.57	.040
Shortleaf	2,449	58	12.2	.37 to .72	.52	.043
Slash	931	30	11.0	.41 to .70	.53	.040
Sand	151	48	9.1	.41 to .65	.48	.042
Virginia	244	44	9.8	.40 to .60	.50	.037
White	559	48	15.6	.25 to .54	.35	.033

For loblolly pine (see fig. 2), specific gravity values averaged higher in the gulf coastal and Atlantic coastal regions than in areas inland. Specific gravity values increased from north to south, particularly in the western part of the range and along the Atlantic coast, but not in the Piedmont region of North Carolina, South Carolina, and Georgia. These results are in general agreement with those of Zobel et al. (1960), who also reported that specific gravity values of loblolly pine increase from north to south along the southeast coastal region but not in the inland region of the Piedmont. Similar north-south trends were reported in Mississippi by Mitchell and Wheeler (1959) and in the mid-South by the Forest Products Laboratory (U. S. D. A. Forest Service 1965). Changes in specific gravity with geography have generally been associated with moisture availability: Mitchell and Wheeler (1959) and Larson (1957) have made such correlations. It is possible that the trends displayed by the data in this study are also associated with moisture, but the lack of supporting information regarding moisture conditions at specific locations does not permit such an analysis. Although an east-west trend has been reported for other species, neither these data nor the Forest Products Laboratory report (U. S. D. A. Forest Service 1965) gave evidence of such a trend for loblolly pine.

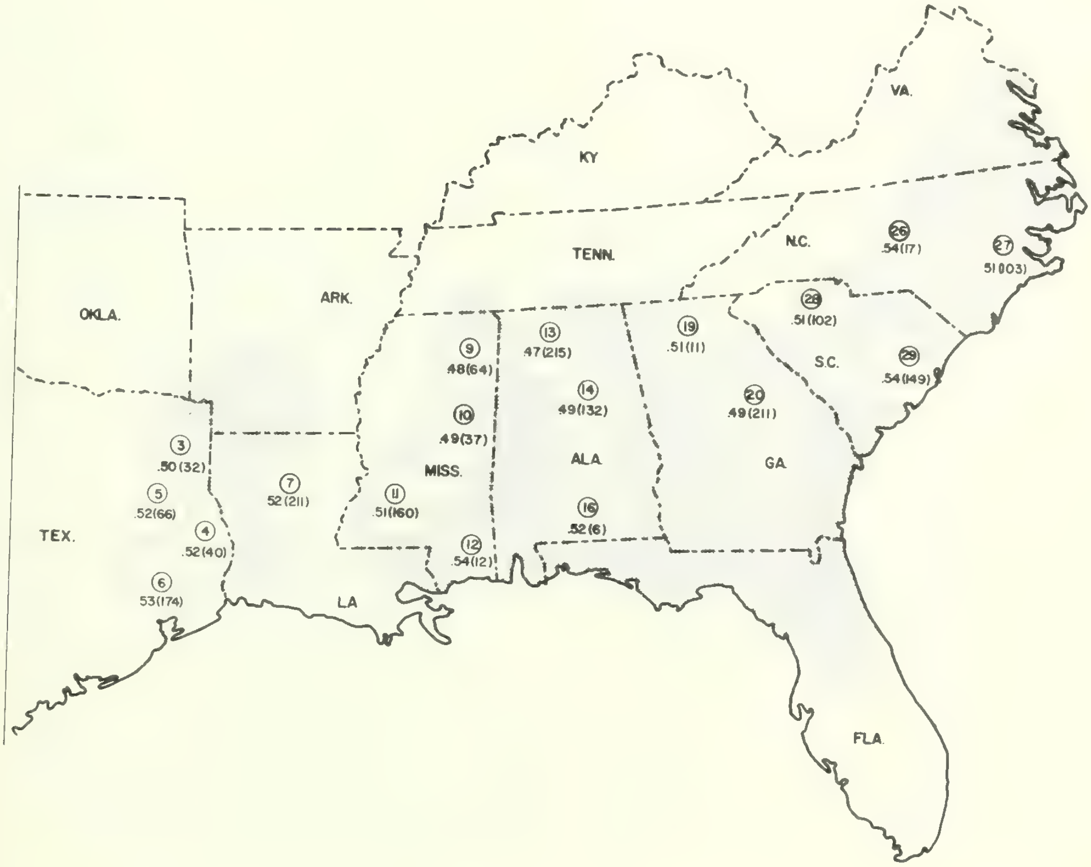

Figure 2.--LOBLOLLY PINE: Average specific gravity and number of sample trees (in parentheses). Circled numbers indicate National Forest areas. The shaded area is the southern portion of the natural growing range of the species.

For longleaf pine (see fig. 3), specific gravity values from the sample areas in Florida averaged higher (0.59 to 0.61) than did those from all the other locations (0.55 to 0.58). Specific gravity values increased from north to south in Texas, Alabama, and along the Atlantic coast from North Carolina to central Florida. An east-west trend was also evident in this species; specific gravity values increased from a low of 0.55 in the west (average of 3 locations in Texas) to a high of 0.60 in the east (average of 3 locations in Florida). Where sample locations are comparable, the results for this species are very similar to those reported by the Forest Products Laboratory (U. S. D. A. Forest Service 1965).

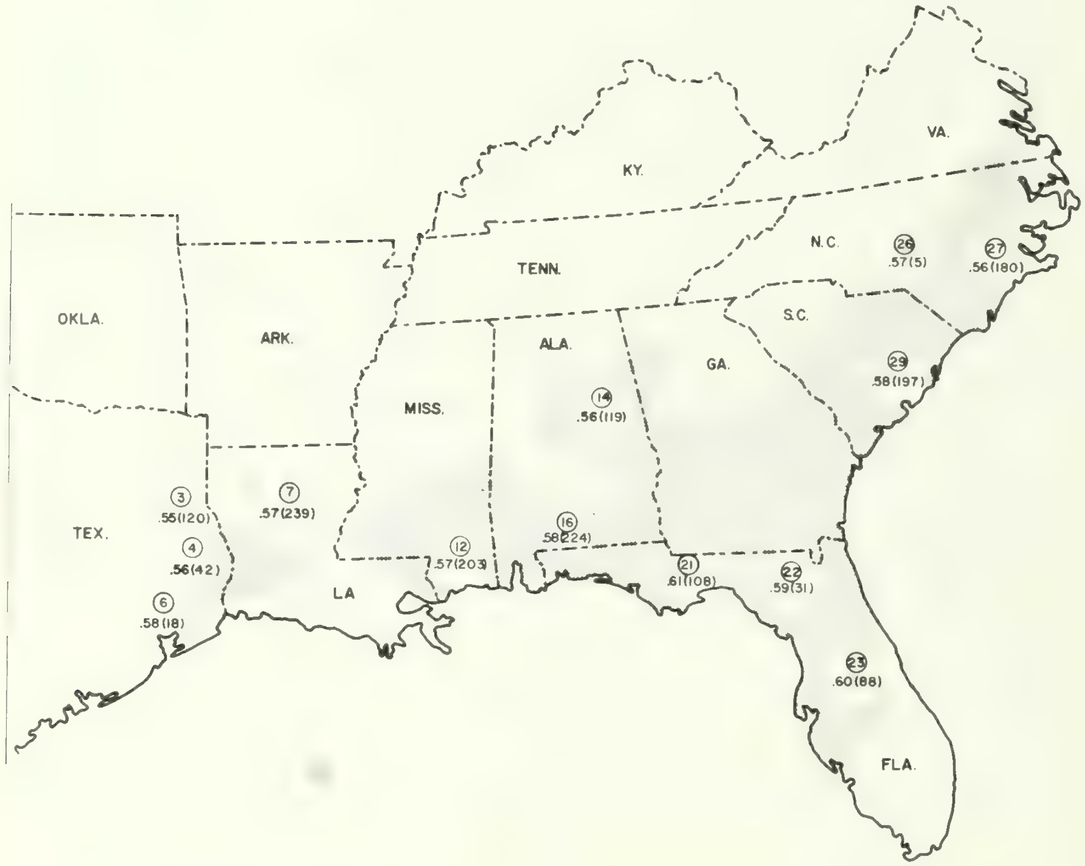

Figure 3.--LONGLEAF PINE: Average specific gravity and number of sample trees (in parentheses). Circled numbers indicate National Forest areas. The shaded area is the natural growing range of the species.

For shortleaf pine (see fig. 4), specific gravity values averaged highest in southeast Mississippi (0.55). Unlike the other major southern pine species examined, shortleaf did not exhibit an overall north-south or east-west geographic trend in specific gravity. An exception was a north-south trend in east Texas and from location 17 in Kentucky to location 20 in central Georgia, but the central Georgia sample was small and perhaps not representative for that location. The specific gravity values at individual sample locations such as 6, 12, and 20 were higher than average; but there was no particular pattern of variation among sample locations. Data presented by Wheeler and Mitchell (1962) for trends of shortleaf pine in Mississippi are not confirmed by these data.

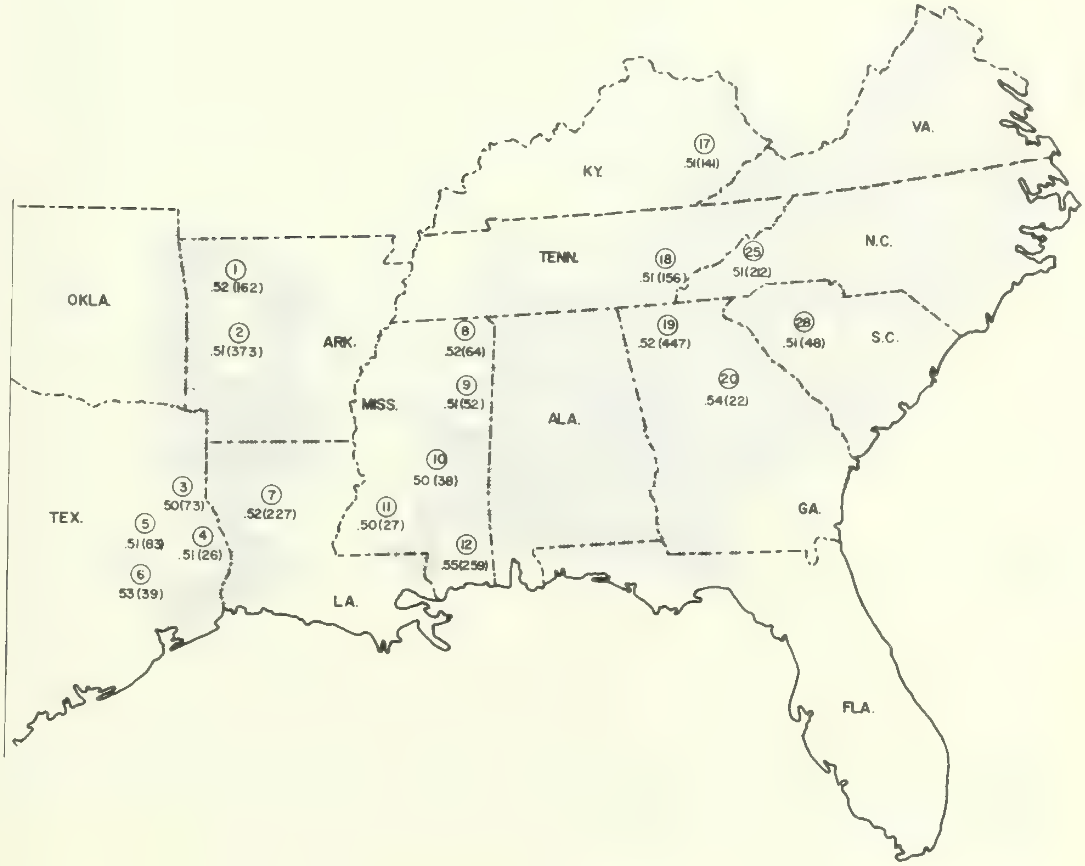

Figure 4.--SHORTLEAF PINE: Average specific gravity and number of sample trees (in parentheses). Circled numbers indicate National Forest areas. The shaded area is the southern portion of the natural growing range of the species.

For slash pine (see fig. 5), specific gravity values averaged highest in Florida (0.57 to 0.60). Specific gravity values increased from north to south in Alabama (0.52 to 0.53) and in Florida (0.57 to 0.60). An east-west trend was also evident; specific gravity values increased from 0.51 in the west (one location in Louisiana)[2] to 0.57 in the east (average of three locations in Florida). These data are in agreement with the results of Larson (1957), Perry and Wu (1958), and Goddard and Strickland (1962).

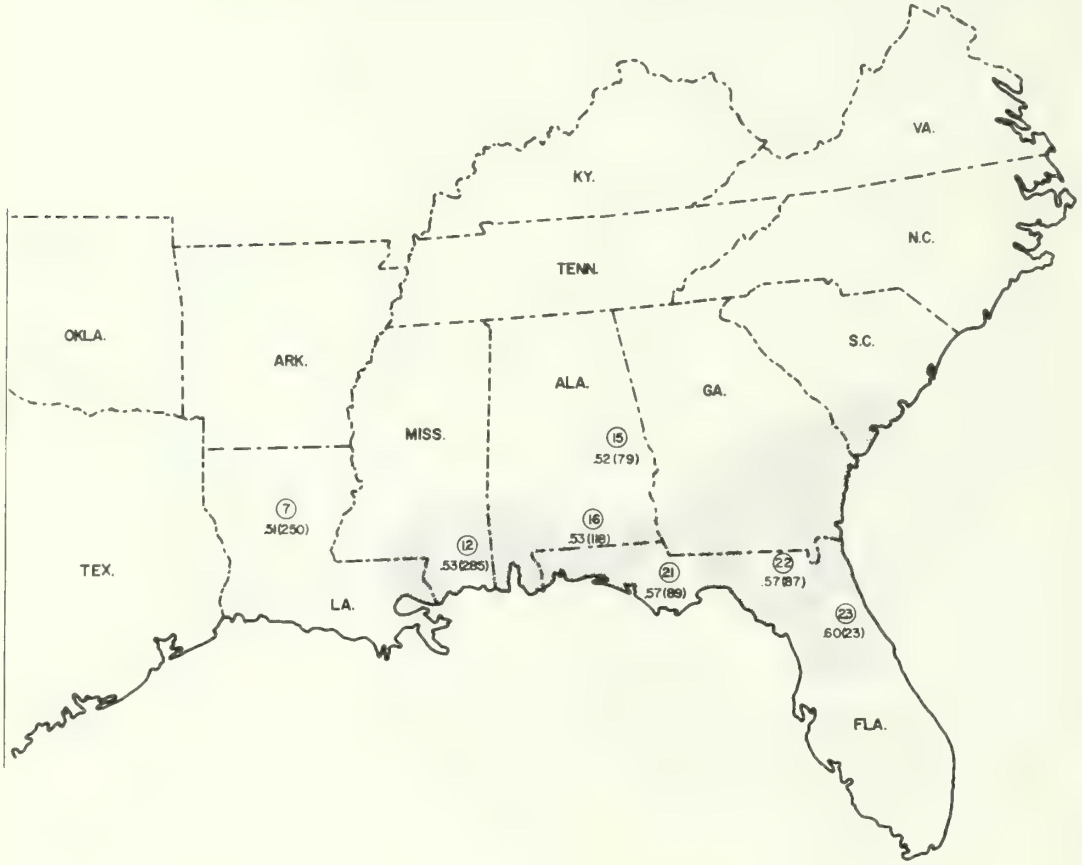

Figure 5.--SLASH PINE: Average specific gravity and number of sample trees (in parentheses). Circled numbers indicate National Forest areas. The shaded area is the natural growing range of the species.

Sand pine, which occurs only in central and western Florida, was sampled in central Florida and had an average specific gravity of 0.48. Virginia pine was sampled in north Georgia and east Tennessee and had an average specific gravity of 0.50. Eastern white pine was sampled at four locations in the southern Appalachian region and had an average specific gravity of 0.35. No pattern of geographic variation was evident among these four locations except that the trees of one location on the western side of the Appalachian Mountains in Tennessee had a higher average specific gravity, but a smaller average d.b.h., than did trees on the eastern side of the mountains in Georgia and North Carolina.

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[2] This location in Louisiana (7) is outside the natural range of slash pine. Samples from this location were from plantation trees which averaged 29 years of age.

SUMMARY AND CONCLUSIONS

This study, like previous studies, indicates that small but real differences in mean specific gravity occur in the major southern pine species with geographic location, and that variation among individuals within locations is greater than the mean differences between locations. Shortleaf pine, however, appears to be an exception; its mean specific gravity does not vary greatly between geographic locations. The increase in specific gravity values from north to south and west to east is not always discrete and well defined; but, in this, as in previous studies, the highest specific gravity values are found in locations along the south Atlantic and gulf coasts and in the Florida peninsula.

It is not known whether the difference between specific gravity values in coastal areas and in inland areas is environmentally induced or results from the existence of genetic clines. In either case, the results of seed source studies presently underway should provide us with a better understanding of why these differences occur.

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APPENDIX

Table 3.--Specific gravity by species and National Forests of Region 8, U.S.D.A. Forest Service

LOBLOLLY PINE

Location No.	National Forest	Sample trees	Mean age	Mean d.b.h.	Specific gravity		
					Range	Mean	Standard deviation
		Number	Years	Inches			
3	Sabine E. Cent. Tex.	32	43	14.9	.43 to .56	.50	.034
4	Angelina E. Cent. Tex.	40	52	16.9	.41 to .60	.52	.037
5	Davy Crockett E. Cent. Tex.	66	53	16.0	.46 to .61	.52	.034
6	Sam Houston SE. Tex.	174	52	14.6	.44 to .67	.53	.039
7	Kisatchie Cent. La.	211	53	17.7	.40 to .67	.52	.039
9	Tombigbee N. Cent. Miss.	64	48	14.5	.42 to .56	.48	.033
10	Bienville Cent. Miss.	37	46	14.0	.41 to .58	.49	.035
11	Homochitto SW. Miss.	160	45	16.6	.44 to .59	.51	.033
12	DeSoto SE. Miss.	12	48	13.3	.50 to .57	.54	.017
13	Bankhead NW. Ala.	215	46	12.4	.38 to .57	.47	.030
14	Talladega Cent. Ala.	132	48	13.9	.43 to .60	.49	.033
16	Conecuh S. Cent. Ala.	6	37	14.2	.43 to .57	.52	.052
19	Chattahoochee N. Ga.	11	39	11.1	.43 to .68	.51	.065
20	Oconee Cent. Ga.	211	43	13.7	.39 to .64	.49	.034
26	Uwharrie Cent. N.C.	17	49	14.7	.48 to .56	.54	.023
27	Croatan E. N.C.	103	45	14.7	.42 to .59	.51	.033
28	Sumter W. S.C.	102	40	12.9	.42 to .61	.51	.032
29	Francis Marion E. S.C.	149	47	16.2	.41 to .65	.54	.036

Table 3.--Specific gravity by species and National Forests of Region 8, U. S. D. A. Forest Service (continued)

LONGLEAF PINE

Location No.	National Forest	Sample trees	Mean age	Mean d. b. h.	Specific gravity		
					Range	Mean	Standard deviation
		Number	Years	Inches			
3	Sabine E. Cent. Tex.	120	32	9.5	.46 to .66	.55	.040
4	Angelina E. Cent. Tex.	42	46	11.6	.46 to .73	.56	.059
6	Sam Houston SE. Tex.	18	54	12.7	.53 to .66	.58	.034
7	Kisatchie Cent. La.	239	46	12.6	.40 to .72	.57	.040
9	Tombigbee N. Cent. Miss.	1	56	10.1	--	.60	--
11	Homochitto SW. Miss.	1	51	13.1	--	.55	--
12	DeSoto SE. Miss.	203	42	11.6	.44 to .69	.57	.038
14	Talladega Cent. Ala.	119	51	11.5	.51 to .68	.56	.032
16	Conecuh S. Cent. Ala.	224	39	10.4	.48 to .75	.58	.040
21	Apalachicola NW. Fla.	108	58	10.7	.51 to .75	.61	.042
22	Osceola NE. Fla.	31	50	10.9	.52 to .69	.59	.042
23	Ocala Cent. Fla.	88	55	11.8	.50 to .72	.60	.045
26	Uwharrie Cent. N.C.	5	56	13.6	.50 to .61	.57	.045
27	Croatan E. N.C.	180	66	12.5	.47 to .72	.56	.043
29	Francis Marion E. S.C.	197	63	13.3	.49 to .67	.58	.034

Table 3.--Specific gravity by species and National Forests of Region 8, U.S.D.A. Forest Service (continued)

SHORTLEAF PINE

Location No.	National Forest	Sample trees	Mean age	Mean d.b.h.	Specific gravity		
					Range	Mean	Standard deviation
		Number	Years	Inches			
1	Ozark NW. Ark.	162	54	11.8	.43 to .62	.52	.038
2	Ouachita W. Cent. Ark.	373	58	12.3	.42 to .68	.51	.038
3	Sabine E. Cent. Tex.	73	40	11.1	.41 to .72	.50	.057
4	Angelina E. Cent. Tex.	26	46	11.5	.47 to .55	.51	.022
5	Davy Crockett E. Cent. Tex.	83	56	13.4	.43 to .59	.51	.032
6	Sam Houston SE. Tex.	39	44	11.2	.48 to .59	.53	.032
7	Kisatchie Cent. La.	227	54	13.0	.41 to .64	.52	.039
8	Holly Springs N. Miss.	64	68	13.0	.39 to .63	.52	.043
9	Tombigbee N. Cent. Miss.	52	56	13.8	.43 to .58	.51	.034
10	Bienville Cent. Miss.	38	50	12.0	.41 to .57	.50	.039
11	Homochitto SW. Miss.	27	49	14.0	.42 to .58	.50	.034
12	DeSoto SE. Miss.	259	50	11.6	.44 to .68	.55	.042
17	Daniel Boone Cent. Ky.	141	71	12.4	.37 to .67	.51	.045
18	Cherokee E. Tenn.	156	54	10.4	.40 to .69	.51	.046
19	Chattahoochee N. Ga.	447	70	13.0	.42 to .70	.52	.044
20	Oconee Cent. Ga.	22	54	12.3	.48 to .60	.54	.030
25	Nantahala W. N.C.	212	53	10.8	.40 to .68	.51	.048
28	Sumter W. S.C.	48	60	13.9	.44 to .60	.51	.037

Table 3.--Specific gravity by species and National Forests of Region 8, U. S. D. A. Forest Service (continued)

SLASH PINE

Location No.	National Forest	Sample trees	Mean age	Mean d.b.h.	Specific gravity		
					Range	Mean	Standard deviation
		Number	Years	Inches			
7	Kisatchie Cent. La.	250	29	11.6	.41 to .66	.51	.039
12	DeSoto SE. Miss.	285	30	11.3	.44 to .66	.53	.038
15	Tuskegee E. Cent. Ala.	79	30	9.1	.44 to .62	.52	.031
16	Conecuh S. Cent. Ala.	118	29	10.4	.46 to .60	.53	.028
21	Apalachicola NW. Fla.	89	35	10.8	.46 to .70	.57	.055
22	Osceola NE. Fla.	87	32	10.4	.50 to .65	.57	.031
23	Ocala Cent. Fla.	23	43	12.3	.50 to .66	.60	.039
SAND PINE							
23	Ocala Cent. Fla.	151	48	9.1	.41 to .65	.48	.042
VIRGINIA PINE							
18	Cherokee E. Tenn.	161	44	9.5	.41 to .60	.51	.037
19	Chattahoochee N. Ga.	83	44	10.4	.40 to .57	.49	.037
WHITE PINE							
18	Cherokee E. Tenn.	205	56	16.1	.25 to .54	.37	.038
19	Chattahoochee N. Ga.	109	52	18.2	.30 to .44	.36	.028
24	Pisgah W. Cent. N.C.	207	37	13.5	.27 to .46	.33	.041
25	Nantahala SW. N.C.	38	58	17.4	.30 to .47	.36	.033

Table 4.--Specific gravity by species and by states

LOBLOLLY PINE

State	Sample trees	Mean age	Mean d.b.h.	Specific gravity		
				Range	Mean	Standard deviation
	Number	Years	Inches			
Alabama	340	48	13.1	.38 to .60	.48	.033
Georgia	222	43	13.6	.39 to .68	.49	.036
Louisiana	211	53	17.6	.40 to .67	.52	.039
Mississippi	280	45	15.4	.41 to .59	.50	.036
North Carolina	126	45	14.7	.42 to .59	.52	.033
South Carolina	251	44	14.9	.41 to .65	.53	.038
Texas	312	51	15.2	.41 to .67	.52	.038
LONGLEAF PINE						
Alabama	344	43	10.8	.48 to .75	.57	.038
Florida	227	56	11.1	.50 to .75	.60	.044
Louisiana	239	46	12.6	.40 to .72	.57	.040
Mississippi	204	42	11.6	.44 to .69	.57	.038
North Carolina	185	66	12.5	.47 to .72	.56	.043
South Carolina	197	63	13.3	.49 to .67	.58	.034
Texas	180	38	10.3	.46 to .73	.55	.045
SHORTLEAF PINE						
Arkansas	487	58	12.1	.42 to .68	.51	.038
Georgia	469	69	13.0	.42 to .70	.52	.044
Kentucky	147	71	12.4	.37 to .67	.51	.045
Louisiana	221	54	13.1	.41 to .64	.52	.039
Mississippi	440	53	12.2	.39 to .68	.53	.045
North Carolina	212	53	11.0	.40 to .68	.51	.050
Oklahoma	48	50	12.0	.43 to .66	.51	.046
South Carolina	48	60	13.9	.44 to .60	.51	.037
Tennessee	156	54	10.4	.40 to .69	.51	.046
Texas	221	47	12.0	.41 to .72	.51	.042
SLASH PINE						
Alabama	197	29	9.9	.44 to .62	.53	.030
Florida	198	34	10.8	.46 to .70	.57	.055
Louisiana	250	29	11.6	.41 to .66	.51	.039
Mississippi	285	30	11.3	.44 to .66	.53	.038
SAND PINE						
Florida	151	48	9.1	.41 to .65	.48	.042
VIRGINIA PINE						
Georgia	83	44	10.4	.40 to .57	.49	.037
Tennessee	161	44	9.5	.41 to .60	.51	.037
WHITE PINE						
Georgia	109	52	18.2	.30 to .44	.36	.028
North Carolina	245	40	14.0	.27 to .47	.34	.032
Tennessee	205	55	16.1	.25 to .54	.37	.038

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